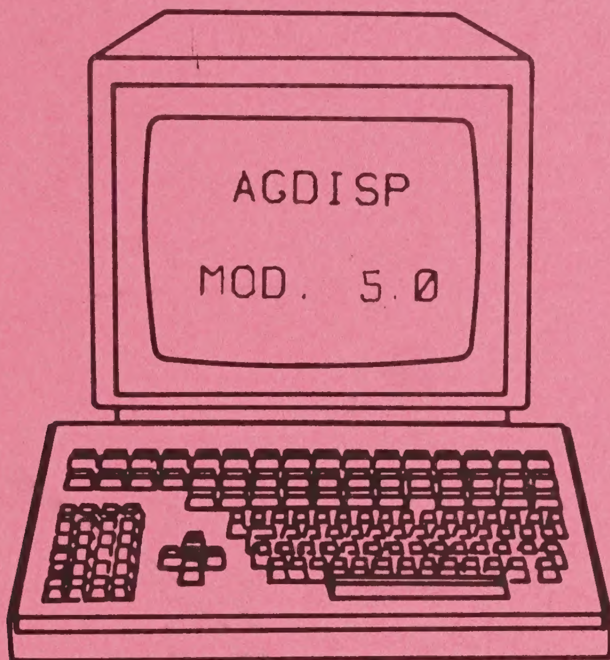
Forest Service

Equipment
Development
Center

Missoula, MT

# User Manual Extension For The Computer Code AGDISP MOD 5.0




PROGRAM WIND
COOPERATIVE ATMOSPHERIC RESEARCH

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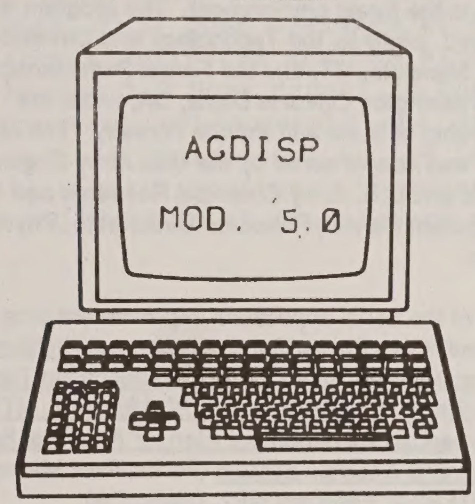
# User Manual Extension For The Computer Code AGDISP MOD 5.0

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## Foreword

This report is published as a part of the USDA Forest Service program to improve aerial application of pesticides, specifically by using pesticides and delivery systems tailored to the forest environment. The program is conducted jointly by the Technology and Development Center, Missoula, MT, and the Forest Pest Management Staff, Washington Office at Davis, CA, under the sponsorship of State and Private Forestry. The MOD 5.0 version was cosponsored by the U.S. Army Dugway Proving Grounds and U.S. Army Chemical Research and Development Center, Research Directorate, Physics Division.

Details of the aerial application improvement program are explained in two Forest Service reports, A Problem Analysis: Forest and Range Aerial Pesticide Application Technology (MTDC Rept. 7934 2804, July l979, Missoula, MT) and Recommended Development Plan for An Aerial Spray Planning and Analysis System (Forest Pest Management Rpt. FPM 82-2, February l982, Davis, CA).

A system of computer models has been developed to optimize spray program design and operation and assess environmental risk posed by aerial spray operations. AGDISP is one of these models, and this user's manual covers the most recent version of AGDISP, MOD 5.0.

AGDISP was developed under the leadership of the National Aeronautics and Space Administration with support by the Forest Service to include special forest spray conditions.

When NASA's Agricultural Aviation Program was terminated, the Forest Service continued to support and direct further development and improvements of the AGDISP model.

The changes and additions that have been incorporated into MOD 5.0 are listed on page ii.

The MOD 5.0 is operational on the USDA Forest Service Data General MV-15000 and is installed with GKS graphics and the IBM PC/XT/AT personal computers.

SUMMARY

The AGDISP computer code predicts the motion of agricultural material released from aircraft, including the mean position of the material and the position variance about the mean as a result of turbulent fluctuations. Developed under sponsorship by NASA, U.S. Department of Agriculture (Forest Service) and U.S. Army Dugway Proving Grounds, this code operates efficiently and is user-friendly, with many of its features validated against wind-tunnel and flight test data. This document is the Mod 5.0 User Manual to the AGDISP code, and includes a description of its current enhancements and operating instructions. This version of the AGDISP code is operational on the following computers: Data General (with GKS graphics); Digital Equipment Corporation VAX (with Calcomp and Tektronix 4025); and IBM PC/XT/AT (with proprietary plotting programs for dot matrix printers).

## MODIFICATION LEVEL

AGDISP code development has lead to the following versions of the code.

**Mod. 2.0** Operational on a Control Data CYBER 175 at NASA-Langley.

Includes: all of the basic program development: fully rolled-up vortices or Betz roll-up, simplified terrain modeling, WAKE plot file entry, models for propeller, helicopter, crosswind, superequilibrium turbulence, canopy, vortex penetration into canopy, and material evaporation. Also includes a stand-alone program (AGLINE) to construct the equivalent Gaussian distribution.

Graphics: Tektronix 4025 and 401X terminals using NASA-Langley graphics software calls.

**Mod. 3.0** Operational on a Univac 1108 at Ft. Collins (U.S. Forest Service).

Improvements: helicopter modeling with transition to rolled-up vortices; AGLINE calculations as a menu option in AGPLOT.

Additions: discrete crosswind velocity profile; nonzero deposition height; composite deposition plots (to 16 plot files); canopy penetration by helicopter downwash; plot option to plot material diameter time history.

Graphics: DISSPLA at Ft. Collins, with appropriate subroutine calls for Tektronix terminals.

**Mod. 4.0** Operational on a VAX 11/785 at Dugway Proving Grounds (U.S. Army).

Improvements: Betz roll-up procedure and propeller model revised; equivalent Gaussian distribution selection criterion is a program decision involving material vertical velocity.

Additions: models for wide body effects, simple vortex circulation decay, jet engines, multiple powerplants and parameterized evaporation; default input file option; plot option to plot material vertical velocity time history.

Graphics: CALCOMP at Dugway, with appropriate subroutine calls for the pen plotter.

| | | |
|---|---|---|
| Mod 5.0 | Operational on a Data General MV-15000 at Missoula, and on IBM PC/XT/AT personal computers. | |
| | Improvements: | Revised solution procedure eliminates integration stepsize dependence on material decay time constant. |
| | Additions: | Axial variation added to all models; ground sprayer; continuous deposition; canopy deposition; deposition on objects. |
| | Graphics: | GKS at Missoula; dot matrix printer output on IBM PC/XT/AT. |

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| | |
|---|---|
| $A$ | plant area fraction |
| $C$ | concentration |
| $C_C$ | effective canopy drag coefficient |
| $C_D$ | material or aircraft drag coefficient |
| $D$ | maximum body diameter |
| $D_p$ | material diameter |
| $D_t$ | target significant dimension |
| $E$ | inertial impaction efficiency |
| $g_i$ | gravity |
| $h_c$ | canopy height |
| $K$ | inertial impaction parameter, Eq. (48) |
| $M_p$ | material mass |
| $M_{plane}$ | ground deposition |
| $q^2$ | mean square turbulence level, equal to $\langle uu \rangle + \langle vv \rangle + \langle ww \rangle$ |
| $r, R$ | radius |
| Re | Reynolds number, Eq. (8) |
| $s$ | aircraft semispan |
| $S$ | wing planform area |
| $t$ | time |
| $T$ | aircraft thrust |
| $u_i$ | fluctuating local fluid velocity |
| $U_i$ | mean local fluid velocity |
| $U_\infty$ | aircraft flight speed |
| $\Delta U$ | incremental axial velocity |
| $v_*$ | friction velocity |
| $v_i$ | fluctuating material velocity $(u,v,w)$ |

NOMENCLATURE (Cont'd)

| | |
|---|---|
| $V_i$ | mean material velocity (U,V,W) |
| $V_{rel}$ | relative velocity, equal to $\lvert U_i - V_i \rvert$ |
| $V_s$ | swirl velocity |
| $w_d$ | downwash velocity |
| $W_t$ | aircraft weight |
| $x_i$ | fluctuating material position (x,y,z) |
| $X_i$ | mean material position (X,Y,Z) |
| $z_c$ | canopy displacement thickness |
| $z_c$ | surface roughness |
| $z_r$ | reference height |
| $\beta$ | leaf capture efficiency |
| $\Gamma$ | circulation |
| $\Gamma_o$ | circulation at the wing centerline |
| $\delta_{ij}$ | Kroneker delta function |
| $\Delta\Theta$ | wet bulb temperature depression |
| $\kappa$ | von Karman constant |
| $\Lambda$ | macroscale length |
| $\mu$ | forward advance ratio |
| $\nu_{air}$ | kinematic viscosity of air |
| $\rho_{air}$ | density of air |
| $\rho_p$ | density of material |
| $\sigma$ | material standard deviation |
| $\tau_e$ | evaporation time scale |
| $\tau_p$ | material relaxation time scale |
| $\tau_\tau$ | turbulent time scale |
| $\phi$ | inertial impaction second parameter, Eq. (49) |

# 1. INTRODUCTION

The original development of AGDISP was motivated by a desire to determine how aircraft-unique wake and propulsion characteristics affect the ground deposition pattern of aerially released material. Material motion was computed by a Lagrangian formulation of the trajectory paths and the solution of ordinary differential equations. Equations for the ensemble averaged turbulent variance of the released material were developed using a locally isotropic spectral density function. Idealized flow field models were constructed for aircraft vortex wakes, helicopter flow fields, propeller swirl, terrain, crosswind, plant canopy and superequilibrium turbulence. The result of this work was the Mod. 2.0 version of AGDISP as reported in Ref. 1 and 2.

Enhancements to this code include additional models for wide body effects, jet engines and vortex circulation decay. Refinements to the code, noteably to the helicopter model and the graphical presentation of the results, proceeded as the code was made operational at additional computer sites (Mod. 3.0, Ref. 3; Mod 4.0, Ref. 4). This document contains the latest model developments compiled in Mod 5.0, operational on the Data General computer at Missoula, the Digital Equipment VAX at Dugway and IBM PC/XT/AT.

This manual is organized as follows. Section 2 summarizes the equation development and the models currently available in the AGDISP code. Section 3 discusses the operation of AGDISP and includes a listing of the code restrictions, error and warning messages that may arise. Section 4 explains the input card options to AGDISP, and Section 5 explains the operation of the companion plotting package AGPLOT. Section 6 examines the test cases used to exercise the AGDISP models, while Section 7 reviews the usage of AGDISP and AGPLOT on the present computer systems. Section 8 highlights the selection of background turbulence level. The Appendices contain an explanation of each subroutine in the code, flow charts of code structure and a listing of significant variables.

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# 2. SUMMARY OF MODELS

A Lagrangian approach is used to develop the equations of motion of discrete material released from aircraft, with the resulting set of ordinary differential equations solved exactly from step to step. The formulation of the material equations, particularly the ensemble averaged approach used to develop turbulent properties of the material-atmospheric interaction, is detailed in Ref. 1. This section of the User Manual examines those variables and nomenclature that are a part of the AGDISP code results.

The aircraft is assumed to be in level flight near the surface, releasing material into a $(y,z)$ plane normal to the flight direction, $-x$, as shown in Figure 2-1. The AGDISP code solves for the transport of this material within this plane, until it deposits upon the surface or is carried aloft by wind or vortex motions. Accuracy of predictions requires accurate description of background environment (mean winds and turbulence). The need for accuracy must, however, be balanced by the requirement of computational speed and ease of calculation. Simulations need to be performed simply and repeatedly under a variety of background conditions, with minimum computer demands and setup requirements. When the need is justified, the solution for the background environment may be found by a larger, more detailed code, such as the NASA WAKE code discussed in Ref. 5. The mean velocity and turbulence profiles predicted by these codes may then be read by AGDISP to predict released material behavior. As an alternate approach the AGDISP code has been fitted with extensive simplified flow field options to permit the prediction of material motion in a wide range of idealized background conditions. These models are summarized in this section of the User Manual.

The released material is assumed to be spherically shaped. The material flight path as a function of time after release is computed as the locations $(X,Y,Z)$ for all material included in the simulation. The material velocity is denoted by $(U,V,W)$. The material is affected by the background environment; however, the environment is assumed to be unaffected by the presence of the material. The interaction of the material with the turbulence in the environment creates turbulent correlation functions for the position and velocity, $\langle yv \rangle$ and $\langle zw \rangle$; for the velocity variance, $\langle vv \rangle$ and $\langle ww \rangle$; and for the position variance, $\langle yy \rangle$ and $\langle zz \rangle$. The square root of these last two variables gives the horizontal and vertical standard deviations of the material motion about the mean described by $Y$ and $Z$.

## Material Equations of Motion

In the AGDISP code the released material is assumed to be influenced by two forces:

a) weight, and
b) aerodynamic drag.

The governing equations are derived in Ref. 1 and repeated here for completeness.

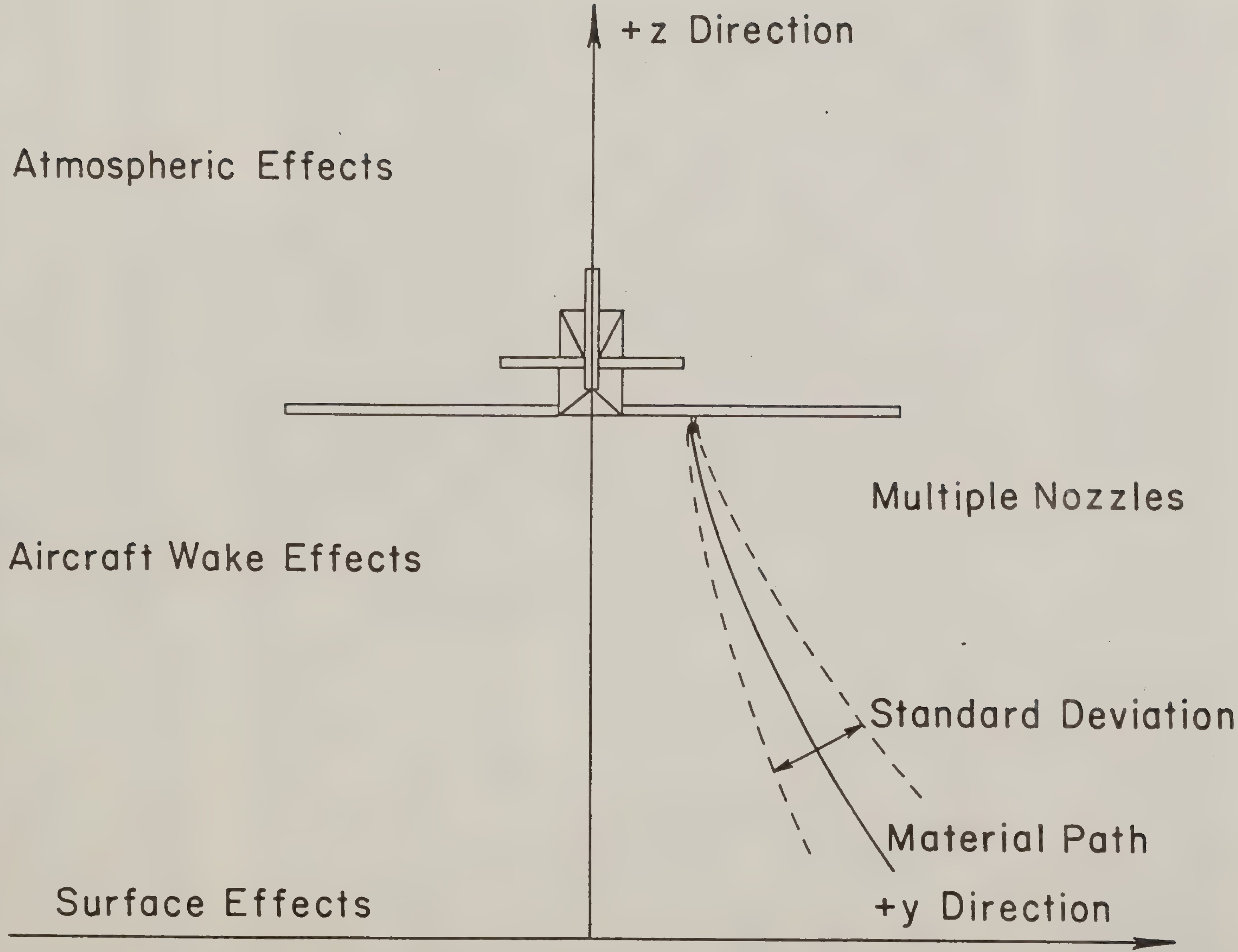



Figure 2-1. Schematic of the calculation plane of the AGDISP code. The aircraft is assumed to be in level flight into the figure. The positive x direction is out of the figure.

Mean Equations

$$\frac{d^2X_i}{dt^2} = (U_i - V_i) \left[\frac{1}{\tau_p}\right] + g_i \qquad (1)$$

$$\frac{dX_i}{dt} = V_i \qquad (2)$$

Turbulent Correlations

$$\frac{d}{dt} \langle x_i x_i \rangle = 2\langle x_i v_i \rangle \qquad (3)$$

$$\frac{d}{dt} \langle x_i v_i \rangle = \left(\langle x_i u_i \rangle - \langle x_i v_i \rangle\right) \left[\frac{1}{\tau_p}\right] + \langle v_i v_i \rangle \qquad (4)$$

$$\frac{d}{dt} \langle v_i v_i \rangle = 2\left(\langle u_i v_i \rangle - \langle v_i v_i \rangle\right) \left[\frac{1}{\tau_p}\right] \qquad (5)$$

In Eqs. (1) - (5), $X_i$, $V_i$ and $U_i$ are the ensemble averaged ith component of material position, velocity and local fluid velocity, respectively, while $x_i$, $v_i$ and $u_i$ are the fluctuating ith component of material position, velocity and local fluid velocity, respectively.

Inherent in the material equations is a relaxation time $\tau_p$ which is essentially the e-folding time for the released material to come up to speed with the local fluid velocity (for $V_i$ to approach and equal $U_i$). The relaxation time is defined as

$$\tau_p = \frac{4}{3} \frac{D_p \rho_p}{C_D V_{rel} \rho_{air}} \qquad (6)$$

where $D_p$ is the diameter of the material, $\rho_p$ is its density, $\rho_{air}$ is the density of air, $V_{rel}$ is the relative velocity between the material and the local background, and $C_D$ is the material drag coefficient. The semi-empirical formula for $C_D$ (Ref. 6) is

$$C_D = \frac{24}{Re}\left(1 + 0.197Re^{0.63} + 2.6 \times 10^{-4} Re^{1.38}\right) \tag{7}$$

where Re is the Reynolds number defined as

$$Re = \frac{D_p V_{rel}}{\nu_{air}} \tag{8}$$

The material diameter $D_p$ is affected by evaporation (Ref. 7) as

$$\frac{1}{D_p}\frac{dD_p}{dt} = \frac{-1}{2\tau_e\left(1 - \frac{t}{\tau_e}\right)} \tag{9}$$

where $\tau_e$ is the e-folding evaporation time

$$\tau_e = \frac{D_p^2}{\beta\Delta\Theta} \tag{10}$$

where $\Delta\Theta$ is the wet bulb depression in °C and $\beta$ is defined as

$$\beta = 84.76\left[1.0 + 0.27\ Re^{1/2}\right] \tag{11}$$

in units of $m^2$/sec - °C .

In a recent set of tests (Ref. 8), the evaporation model described by Eq. (9) was compared with wind tunnel results. A typical comparison is shown in Figure 2-2, illustrating favorable agreement with the test data.

Equations (1) - (5) cannot be solved without specifying relationships for the quantities $\langle x_i u_i \rangle$ and $\langle u_i v_i \rangle$ , the correlations of the material position and velocity fluctuations, respectively, with the local fluid velocity fluctuation. These expressions are developed by integrating their ensemble averaged frequency spectra using a spectral density function for transverse velocity fluctuations in isotropic turbulence (Ref. 9). The results (detailed in Ref. 1) give

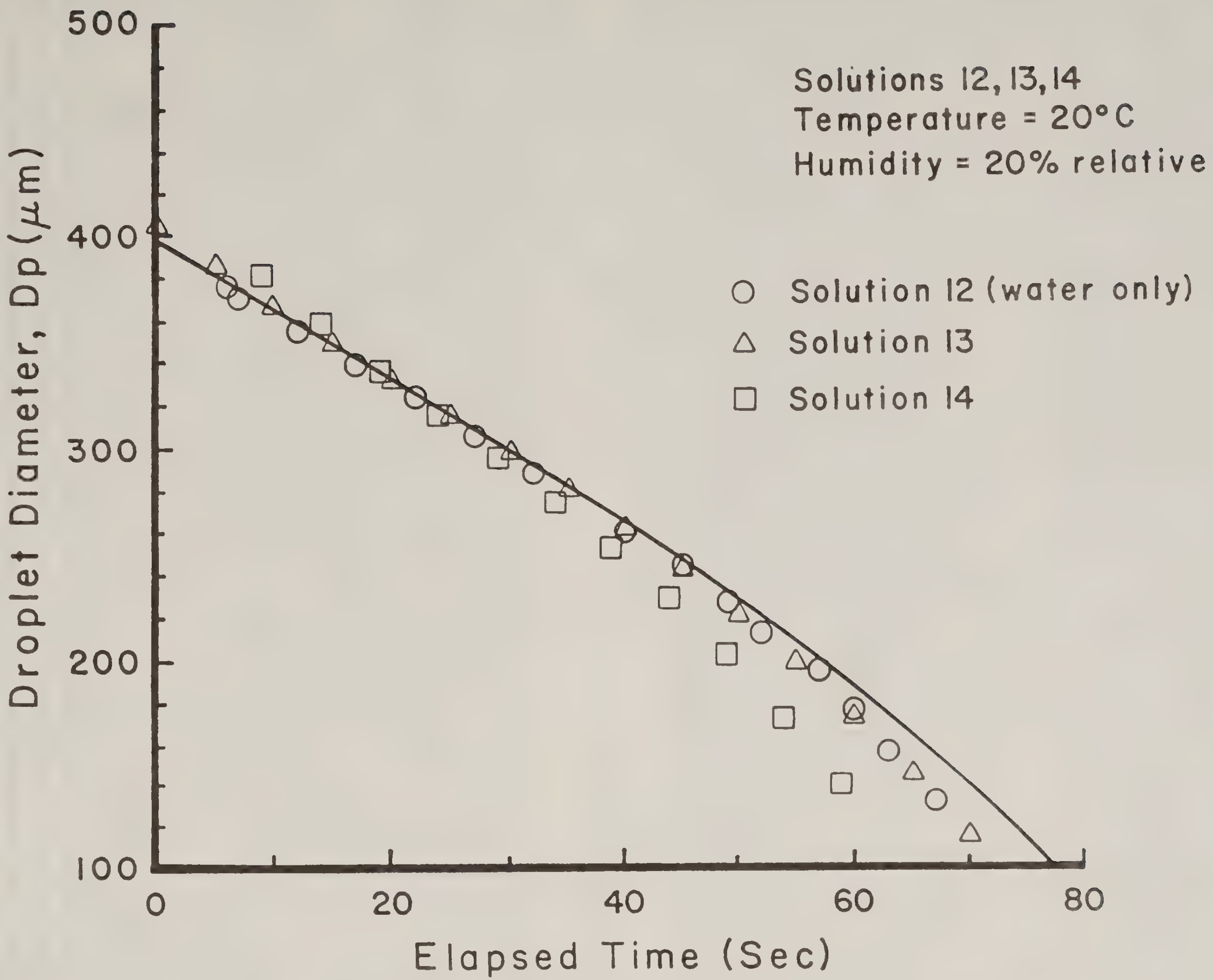



Figure 2-2. Prediction and measurement of droplet diameter variation with time as a consequence of evaporation (Ref. 8).

$$\langle x_i u_i \rangle = \frac{q^2}{3}\left[-\tau_p K + \frac{\tau_\tau}{2}\right] \tag{12}$$

$$\langle u_i v_i \rangle = \frac{q^2}{3} K \tag{13}$$

with

$$K = \frac{1}{2}\,\frac{\left[3 - \left(\frac{\tau_p}{\tau_\tau}\right)^2\right]\left[1 - \frac{\tau_p}{\tau_\tau}\right] + \left(\frac{\tau_p}{\tau_\tau}\right)^2 - 1}{\left[1 - \left(\frac{\tau_p}{\tau_\tau}\right)^2\right]^2} \tag{14}$$

where $\tau_\tau$ is the travel time of the material through a turbulent eddy of scale $\Lambda$, adjusted for the passive tracer limit

$$\tau_\tau = \frac{\Lambda}{V_{rel} + \frac{3}{8} q} \tag{15}$$

The quantity $q^2$ is the mean square turbulence level in the fluid.

With the position and velocity information available for all released material at any time during the simulation, Eqs. (1) - (5) may be integrated exactly for the solution at the next time step. This step result may then serve as initial conditions for the next step integration, etc., through the entire simulation. The assumption that the background conditions $U_i$, $\langle x_i u_i \rangle$ and $\langle u_i v_i \rangle$ are constant across a time step permits solution of Eqs. (1) - (5) unrestricted by the size of the released material. Computational solution times are reduced significantly, and heretofore unsolveable material diameters (including the passive tracer limit, $D_p = 0$ ) may be tracked by the equations.

## Flow Field Modeling

The behavior of the released material is intimately connected to the local background mean velocity $U_i$ and turbulence field $q^2$ through which the material is transported. The AGDISP code has been configured to accept user specified mean velocity and turbulence flow fields in neutral atmospheres, but also contains a number of simplified models for the flow field velocity and turbulence levels behind aircraft. These models are summarized below.

## FIXED-WING FULLY ROLLED-UP TIP VORTICES

When an aircraft flies at a constant altitude, the aerodynamic lift generated by the lifting surfaces of the aircraft equals the aircraft weight. The majority of the lift is carried by the wings, and generates one or more pairs of swirling masses of air (vortices) downstream of the aircraft. If the roll-up of this trailing vorticity can be approximated as occurring immediately downstream of the wing, then the mean velocity field that results may be simply characterized by the aircraft semispan, $s$, circulation, $\Gamma$, and load distribution (Figure 2-3).

## FIXED-WING BETZ ROLL-UP

When the wing loading cannot be approximated by a single vortex pair, or the aircraft is flying sufficiently fast that roll-up cannot be assumed to occur immediately downstream of the wing, then the Betz methodology (Ref. 10) can be employed. The solution procedure (documented in Ref. 11) relates the swirling velocity distribution in the vortices to the details of the wing spanwise load distribution by assuming that angular momentum is approximately conserved. For complicated wing planform shapes, a vortex lattice analysis must be invoked to generate the wing spanwise load distribution (Ref. 12). In a simulation involving the Betz methodology, the vortex sheet rolls into the vortex as a function of time. Thus, the unrolled sheet will contribute to the ambient fluid velocity during the roll-up process.

## VORTEX CIRCULATION DECAY

The flow field generated by a simply loaded wing includes four vortices: the two from either wing tip, and image vortices below the surface (Figure 2-4). The local ambient velocity is the vector sum of the four swirl velocity components, each written as

$$V_s = \frac{\Gamma}{2\pi r} \tag{16}$$

with its direction measured perpendicular to a line connecting each vortex centroid and the observation point. The observation point could be a material position or the location of another vortex (which will also move because of the other vortices present in the flow). An inviscid vortex of constant positive circulation strength $\Gamma = \Gamma_0$ will descend toward the surface while increasing the separation distance between its companion vortex.

In the atmosphere, turbulence will act to decay the vortex strength. A simple decay model, developed in Ref. 13, results in a vortex decay of the form

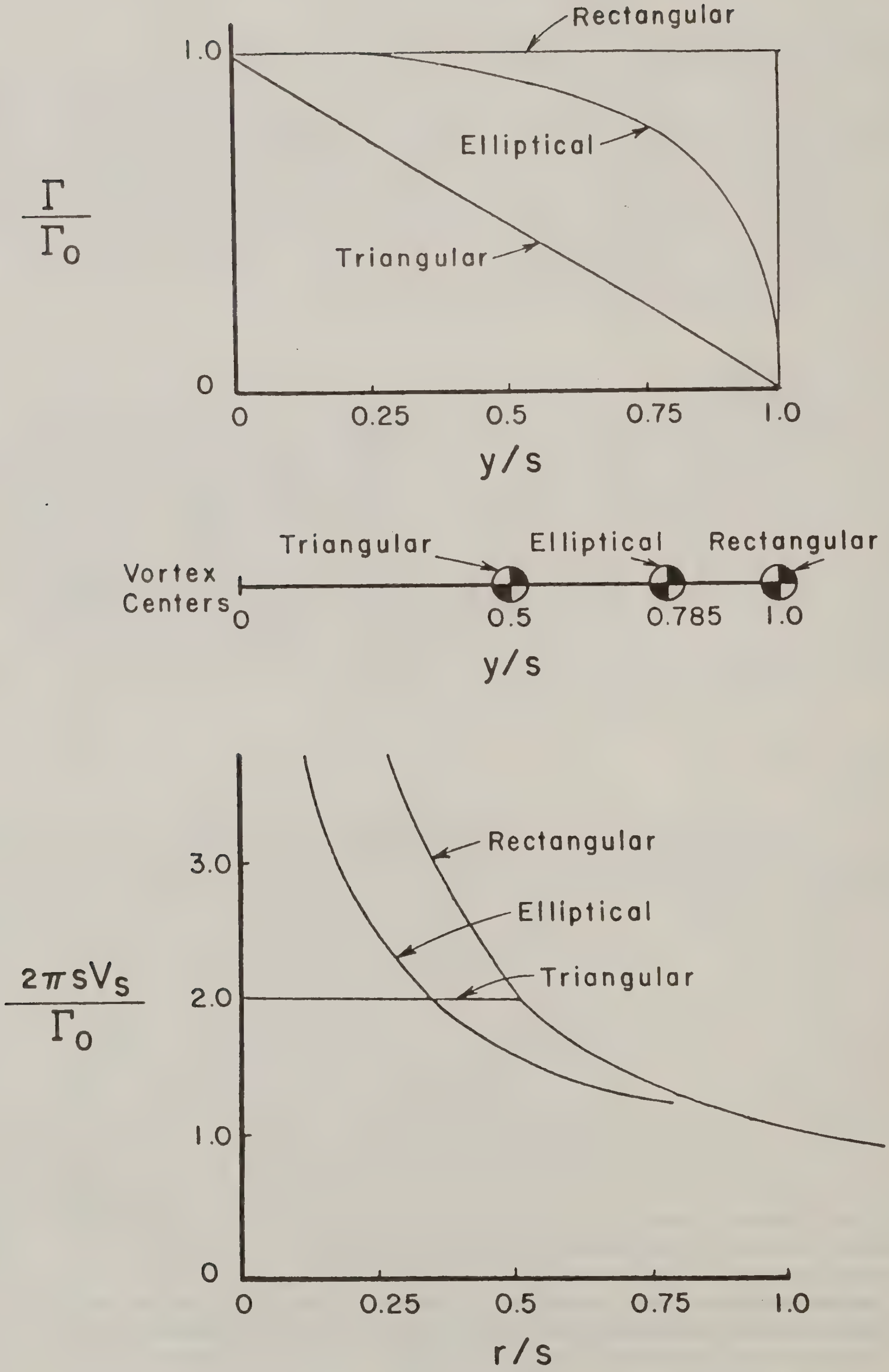



Figure 2-3. Swirl velocity distribution of a fully rolled-up wake as a function of spanwise load distribution and as measured from the center of the resulting vortex.

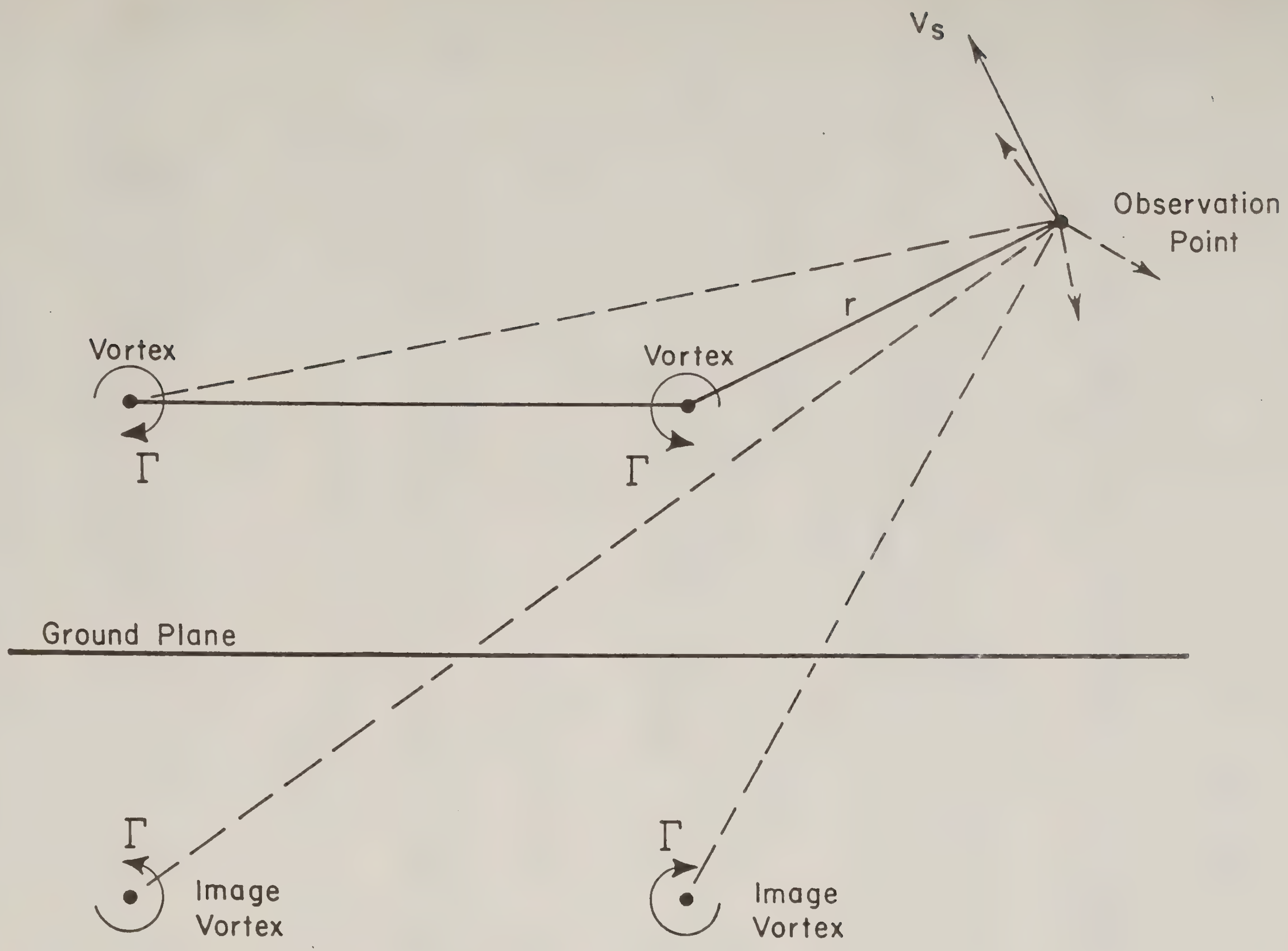



Figure 2-4. The composite velocity vector at an observation point found by summing the contributions of the aircraft vortex pair and its image system below the ground plane.

$$\Gamma = \Gamma_o \exp\left(-\frac{Aqt}{s}\right) \tag{17}$$

For vortices out of ground effect, a typical value for $A = 0.41$ ; while a detailed examination of Program WIND data in ground effect (Ref. 14) gives $Aq = 0.56$ m/s .

HELICOPTER IN FORWARD ADVANCE

The helicopter model includes both the hover downwash and the tip vortex pair by partitioning the helicopter weight between the two effects as a function of time. The hover downwash model is taken from actuator disk theory for a propeller and may be written as

$$FW_t = 2\pi\rho_{air}R^2w_d^2 \tag{18}$$

while the strength of the vortex pair may be found from

$$(1 - F)W_t = 2\rho_{air}RU_\infty\Gamma \tag{19}$$

where $W_t$ is the helicopter weight, $w_d$ is the downwash at the rotor plane, R is the radius of the rotor and $\Gamma$ is the tip circulation strength. The function F is determined by the expression

$$F = \exp\left(-\frac{k\mu\Gamma_o t}{\sigma\pi R^2}\right) \tag{20}$$

where $\mu$ is the forward advance ratio, $\sigma$ is the solidity and $\Gamma_o$ is the solution to Eq. (19) for $F = 0$ . The constant k relates helicopter roll-up (around a circumference at the blade tip) to fixed-wing roll-up. Predicted results from a helicopter wake model (Ref. 15) suggest that the downwash flow field quickly transitions (within two blade revolutions) into a vortex pair. A typical value for $k = 7$ .

The tip vortices influence the flow field everywhere, while the downwash affects only the spreading region beneath the rotor and the fluid column directly above the rotor. Within the boundaries of the rotor blade and the dividing streamline (Figure 2-5), the velocity is assumed to follow a

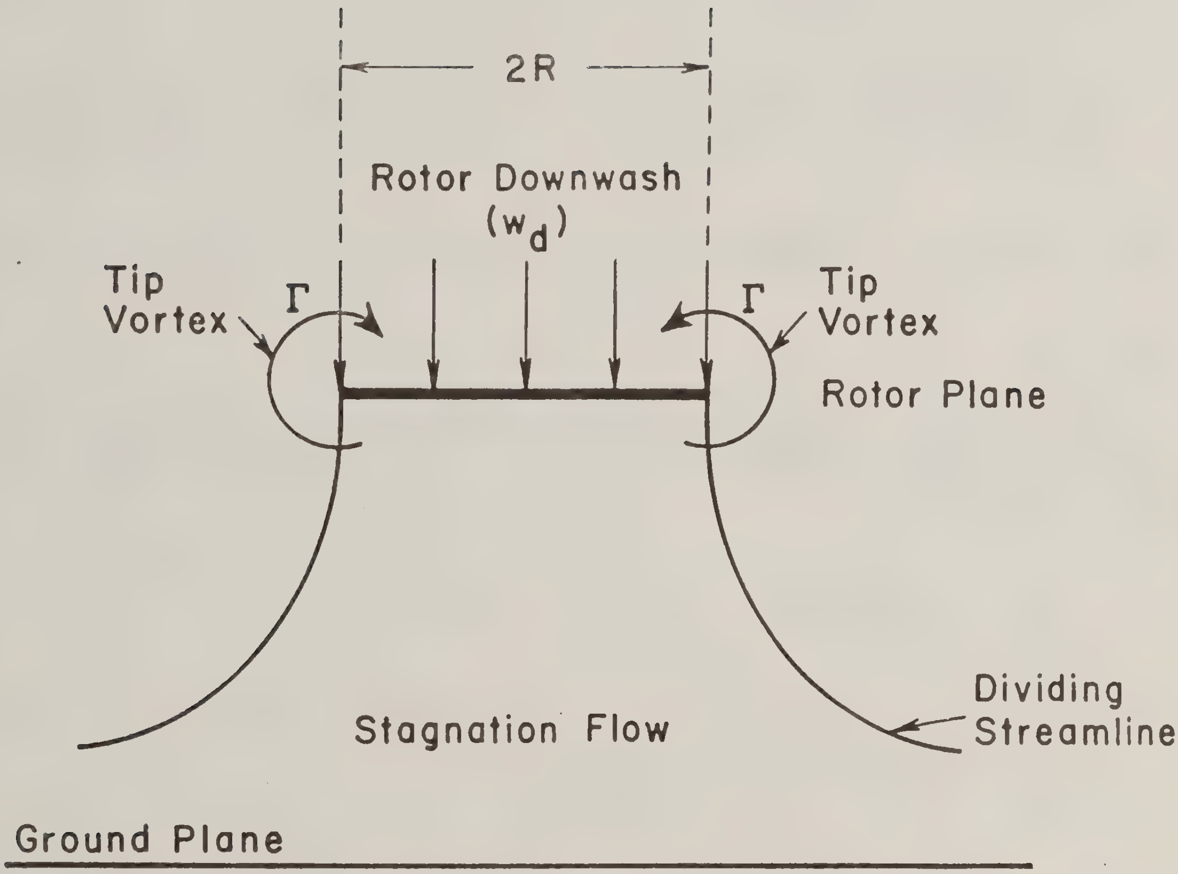



Figure 2-5. Schematic of the helicopter flow field model.

stagnation point flow, while the vortex pair created by the helicopter is assumed to follow the dividing streamline.

Material released ahead of the helicopter (spray boom forward) is assumed to encounter a streamline pattern similar to flow around a circular cylinder (the actuator disk downwash, Ref. 16)

$$U = U_\infty\left(1 - \frac{R^2}{r^2} + \frac{2R^2y^2}{r^4}\right) \tag{21}$$

$$V = -\frac{2U_\infty R^2xy}{r^4} \tag{22}$$

until the material crosses the plane of the helicopter shaft centerline.

## JET ENGINE

The jet engine exhaust is modeled as a turbulent circular jet using the similarity analysis reported in Ref. 17. The results give the axial and radial velocities as

$$u_{axial} = \frac{3}{8\pi}\frac{\sqrt{T/\rho_{air}}}{\varepsilon x}\frac{1}{(1 + \eta^2/4)^2} \tag{23}$$

$$v_{radial} = \frac{1}{4}\sqrt{\frac{3}{\pi}}\frac{\sqrt{T/\rho_{air}}}{x}\frac{(\eta - \eta^3/4)}{(1 + \eta^2/4)^2} \tag{24}$$

with

$$\eta = \frac{1}{4}\sqrt{\frac{3}{\pi}}\frac{\sqrt{T/\rho_{air}}}{\varepsilon}\frac{r}{x} \tag{25}$$

$$\varepsilon = 0.0161\sqrt{T/\rho_{air}} \tag{26}$$

where $T$ is the jet thrust and $x$ is the downstream distance (corrected for the virtual origin). The radial velocity $v_{radial}$ becomes part of the local fluid velocity, while the axial velocity $u_{axial}$ is also used to evaluate the turbulence level

$$q^2 = 0.2034\ u^2_{axial} \tag{27}$$

where the proportionality constant is determined from the centerline decay of turbulence in a free jet (Ref. 18).

PROPELLER

The propeller is modeled as an actuator disk, where the incremental velocity $\Delta U$ over the flight speed $U_\infty$ is related to the actual thrust produced by the propeller

$$T = 2\pi\rho_{air} R^2 \Delta U(U_\infty + \Delta U) \tag{28}$$

where $R$ is the radius of the propeller. In steady flight the thrust equals the aircraft drag, so that

$$T = C_D \frac{1}{2} \rho_{air} U_\infty^2 S \tag{29}$$

where $S$ is the wing planform area and $C_D$ is the aircraft drag coefficient. Combining Eqs. (28) and (29) to eliminate thrust, we obtain

$$\frac{\Delta U}{U_\infty} = \frac{1}{2}\left(-1 + \sqrt{1 + \frac{C_D S}{\pi R^2}}\right) \tag{30}$$

An alternate expression for $\varepsilon$, defined in Eq. (26), may be obtained from Ref. 17 as

$$\varepsilon = 0.0256\ R\Delta U \tag{31}$$

Combining this equation with Eq. (26) gives an effective thrust level for the propeller of

$$T_{eff} = 2.5275\, \rho_{air} R^2 \Delta U^2 \tag{32}$$

to permit the use of Eqs. (23) - (27) for the propeller when Eq. (30) is substituted. The swirl velocity generated by the propeller is assumed to be linear in $R$ out to its maximum value, obtained by integrating the axial flux of angular momentum, and then zero for larger values of $r$. The resulting integration yields

$$V_{tip} = \frac{U_\infty^3 C_D S}{\pi \eta \Omega R^3 (U_\infty + \Delta U)} \tag{33}$$

where $\eta$ is the propeller efficiency and $\Omega$ is the propeller rotational speed.

## WIDE BODY EFFECT

The presence of a significant fuselage shape can generate additional mean velocity and turbulence in the vicinity of the aircraft. For simplicity, we assume that the fuselage cross-sectional area can be modeled as an axisymmetric body shape $B(x)$, where $x$ is measured from the nose to the tail. Slender body theory (Ref. 19) then gives the additional radial velocity contribution from the changing area of

$$v_{radial} = \frac{U_\infty}{2\pi r} B'(x) \tag{34}$$

where the prime denotes a derivative in $x$.

The turbulence level, consistent with the axisymmetric wake created by the passage of the body, is found by matching the data in Ref. 20 with a turbulence model (Ref. 21) and assuming an exponential decay

$$q^2 = q^2_{body} \exp\left[-\frac{1}{2}\left(\frac{r}{R_{1/2}}\right)^2\right] \tag{35}$$

where

$$q^2_{body} = 0.003 U_\infty^2 \left(\frac{x/D}{10}\right)^{-1.43} \tag{36}$$

and

$$R_{1/2} = D\left(\frac{x/D}{100}\right)^{0.33} \tag{37}$$

is the wake radius to half-width, $D$ is equal to the maximum diameter of the body and $x$ is corrected for the virtual origin.

## MEAN CROSSWIND

In a neutral atmospheric surface layer the horizontal velocity follows a logarithmic profile

$$V(z) = V(z_r) \frac{\ln (z/z_o)}{\ln (z_r/z_o)} \tag{38}$$

where $V(z_r)$ is the known horizontal velocity at a given altitude $z_r$, and $z_o$ is the surface roughness. Surface roughness is typically taken to be 1/30th of the actual physical roughness height. With a linear integral scale of turbulence $(\Lambda = 0.65z)$, the turbulence level becomes

$$q^2 = 0.845 \left[\frac{V(z_r)}{\ln (z_r/z_o)}\right]^2 \tag{39}$$

## SUPEREQUILIBRIUM TURBULENCE

The detailed effects of turbulence are obtained by invoking superequilibrium turbulent transport theory (Ref. 22). Superequilibrium refers to the second-order closure turbulence transport model limit where the velocity correlations are able to track their equilibrium values. The nonlinear equations to be solved for the turbulence may be written in index form as

$$\frac{\partial U_m}{\partial x_n} [\delta_{im}\langle u_n u_j\rangle + \delta_{mj}\langle u_i u_n\rangle] + \frac{q}{\Lambda} [\langle u_i u_j\rangle - \frac{1}{3} \delta_{ij} q^2] - \frac{\delta_{ij}}{12} \frac{q^3}{\Lambda} = 0 \tag{40}$$

Since the local mean flow gradients are known, the system of equations represented by Eq. (40) may be solved exactly for $\langle u_i u_j\rangle$ to determine $q^2$.

## PLANT CANOPY

The canopy flow field model is an approximation of the second-order closure turbulence model discussed in Ref. 23. For a canopy of height $h_c$ and plant area fraction $A(z)$, the mean crosswind velocity above the canopy is

$$V(z) = V(z_r) \frac{\ln (z/z_c)}{\ln (z_r/z_c)} \tag{41}$$

where $z_c$ is the displacement thickness of the canopy. Within the canopy the mean velocity and root mean square turbulence levels are assumed linear with height, in good agreement with data (Figure 2-6). The presence of the canopy alters the downwash stagnation flow below the helicopter by moving the effective surface up to $z_c$. Vortices entering the canopy will have decaying circulation strength of the form

$$\frac{\Gamma}{\Gamma_o} = \frac{1}{1 + \frac{\Gamma_o}{2\pi s} f(t)} \tag{42}$$

similar to the atmospheric decay effect in Eq. (17). Here the function $f(t)$ integrates the cumulative effects of $A(z)$ on the circulation of the vortex

$$f(t) = \frac{C_C}{\Delta h} \int_o^t \int_{h_c - \Delta h}^{h_c} A(z) f_A \, dz dt \tag{43}$$

where $C_C$ is the canopy drag coefficient, $\Delta h$ is the penetration depth of the vortex and $f_A$ is the fraction of the vortex within the canopy.

## TERRAIN

Surface slope is modeled by assuming that the ground plane remains straight but may incline. Any vortices in the flow field will have a modified image vortex system to maintain zero flow through the ground. The helicopter downwash model and the position of the dividing streamline are also altered. Crosswind and canopy effects are assumed to remain parallel to the surface.

## GROUND SPRAYER

A ground sprayer is modeled by eliminating the presence of the aircraft vortices and being very specific about the direction and initial velocity of each nozzle.

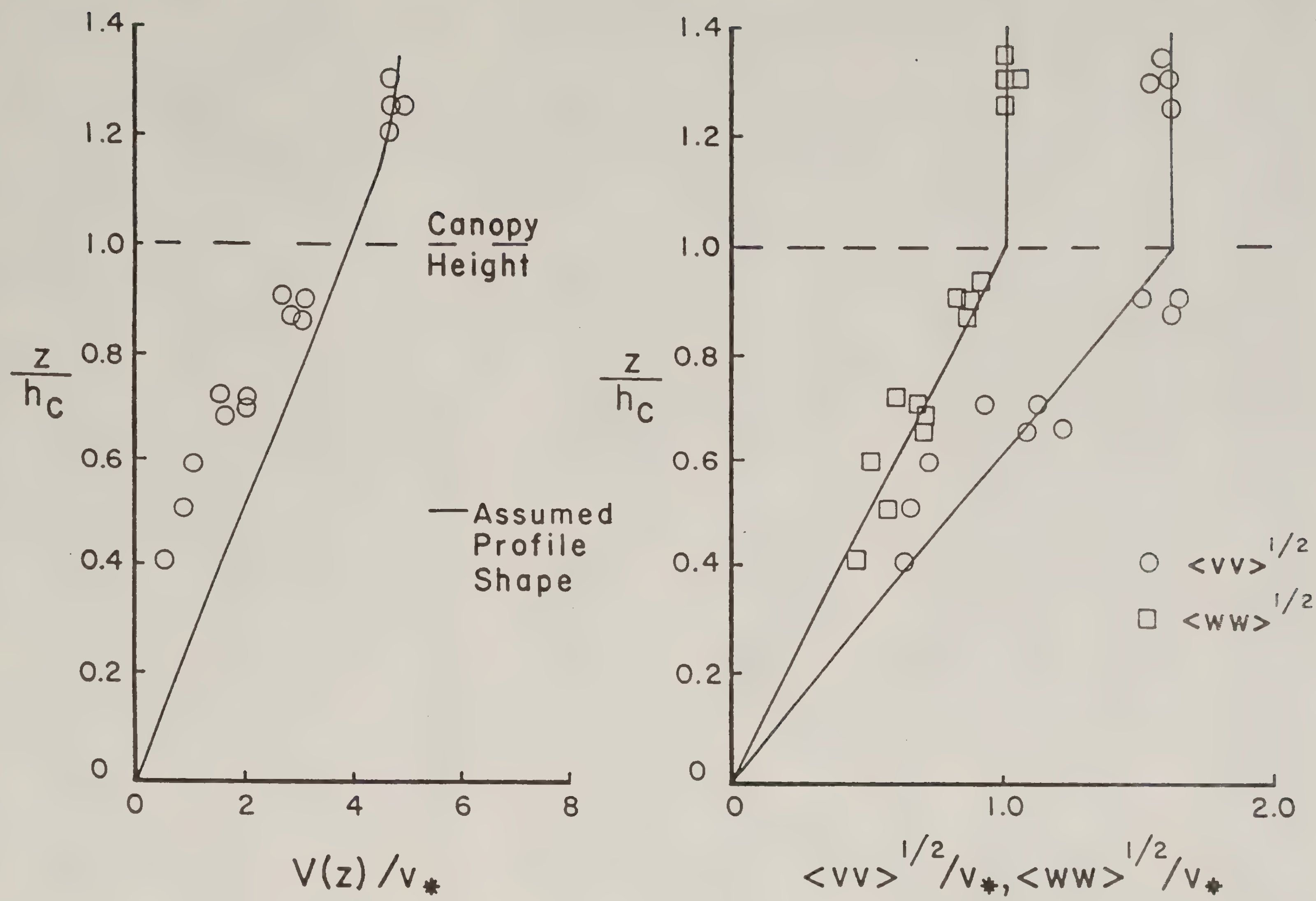



Figure 2-6. Mean wind and root mean square turbulent fluctuations in a canopy (data from Ref. 23), with $v_* = \kappa V(z_r)/\ln(z_r/z_o)$ .

## Deposition Modeling

As material approaches the surface, deposition begins, and continues until all material is deposited (if evaporation occurs, some of the material will be left in the atmosphere to drift). Ground deposition is computed by assuming that the concentration of material around the mean may be taken as Gaussian

$$C = \frac{1}{2\pi\sigma^2} \exp\left[-\frac{(y - Y)^2}{2\sigma^2}\right] \exp\left[-\frac{(z - Z)^2}{2\sigma^2}\right] \tag{44}$$

where the released material is at position $(Y,Z)$ and $(y,z)$ defines its spatial effect.

### GAUSSIAN DEPOSITION

The material is assumed to deposit entirely at the point of surface impact. Here, Eq. (44) is integrated across all z values to give

$$M_{plane} = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(y - Y)^2}{2\sigma^2}\right] \tag{45}$$

### CONTINUOUS DEPOSITION

The material is assumed to deposit incrementally as it approaches the surface, and to continue depositing at its approach rate after impact. Here, Eq. (44) is integrated from negative infinity to the material location to give

$$M_{plane} = \frac{1}{2\sqrt{2\pi}\sigma} \exp\left[-\frac{(y - Y)^2}{2\sigma^2}\right] \text{erfc}\left(\frac{Z}{\sqrt{2}\sigma}\right) \tag{46}$$

where erfc is the complementary error function. The ground deposition is obtained by summing the incremental contributions to $M_{plane}$ as the integration proceeds. It may be seen that for material falling vertically toward the surface, the ground deposition pattern generated by Eq. (46) will be identical to the Gaussian deposition of Eq. (45). The use of Eq. (46) should lead to more realistic ground deposition distributions.

### CANOPY DEPOSITION

When released material traverses a canopy, deposition on the canopy reduces the amount of material available for deposition on lower levels of the canopy or on the surface. The amount of material captured on the canopy vegetation will be directly related to the capture efficiency $\beta$ and the distance traveled by the material through the canopy. Thus, at any time increment $\Delta t$, the deposited material may be found from

$$\Delta C = \beta C A(z)\ \Delta d \tag{47}$$

where $\Delta d$ is the distance traveled in $\Delta t$. The quantity $\Delta C$ reduces the remaining material $C$ available for further deposition.

Equation (47) contains $A(z)$, the plant area fraction. This is essentially a discrete function of height through the canopy, and is the ratio of leaf area (space "occupied" by the tree) divided by the surface area allocated to each typical tree. Reference 24 measured the leaf area for typical almond trees in the Chico orchard. Since the trees were spaced 8.2 meters apart, the surface area for each tree becomes 68 $m^2$. The resulting plant area fraction, discrete at seven heights through the canopy, is shown in Figure 2-7.

## OBJECT DEPOSITION

Equation (44) may also be interpreted to recover the deposition on collection devices (cards, cylinders or spheres) placed at specific locations in the wake flowfield. The total amount of deposition, as computed by Eq. (44), is reduced by the efficiency of the collection device, using the formulas and empirical data found in Ref. 25. The efficiency (as plotted in Figure 2-8 for the three devices) depends on two impaction parameters

$$K = \frac{\rho_p D_p^2 U}{9\rho_{air} \nu_{air} D_t} \tag{48}$$

$$\phi = \frac{9\rho_{air} D_t U}{\nu_{air} \rho_p} \tag{49}$$

The significant target dimension $D_t$ is a typical cross-sectional distance used to characterize the size of the target (for a card, it is the smaller length; for a cylinder, it is the smaller of its diameter or length; for a sphere, it is its diameter). Figure 2-8 demonstrates that as the target dimension increases, $K$ decreases from Eq. (48), $\phi$ increases from Eq. (49), and the collection efficiency decreases (it is easier for a droplet to get out of the way of a big target that significantly disturbs the flowfield than a small target that doesn't).

Material impaction also requires a knowledge of the orientation of the target relative to the solution coordinate system. For the purposes of this analysis, a normal vector must be supplied. This $(x,y,z)$ vector defines the

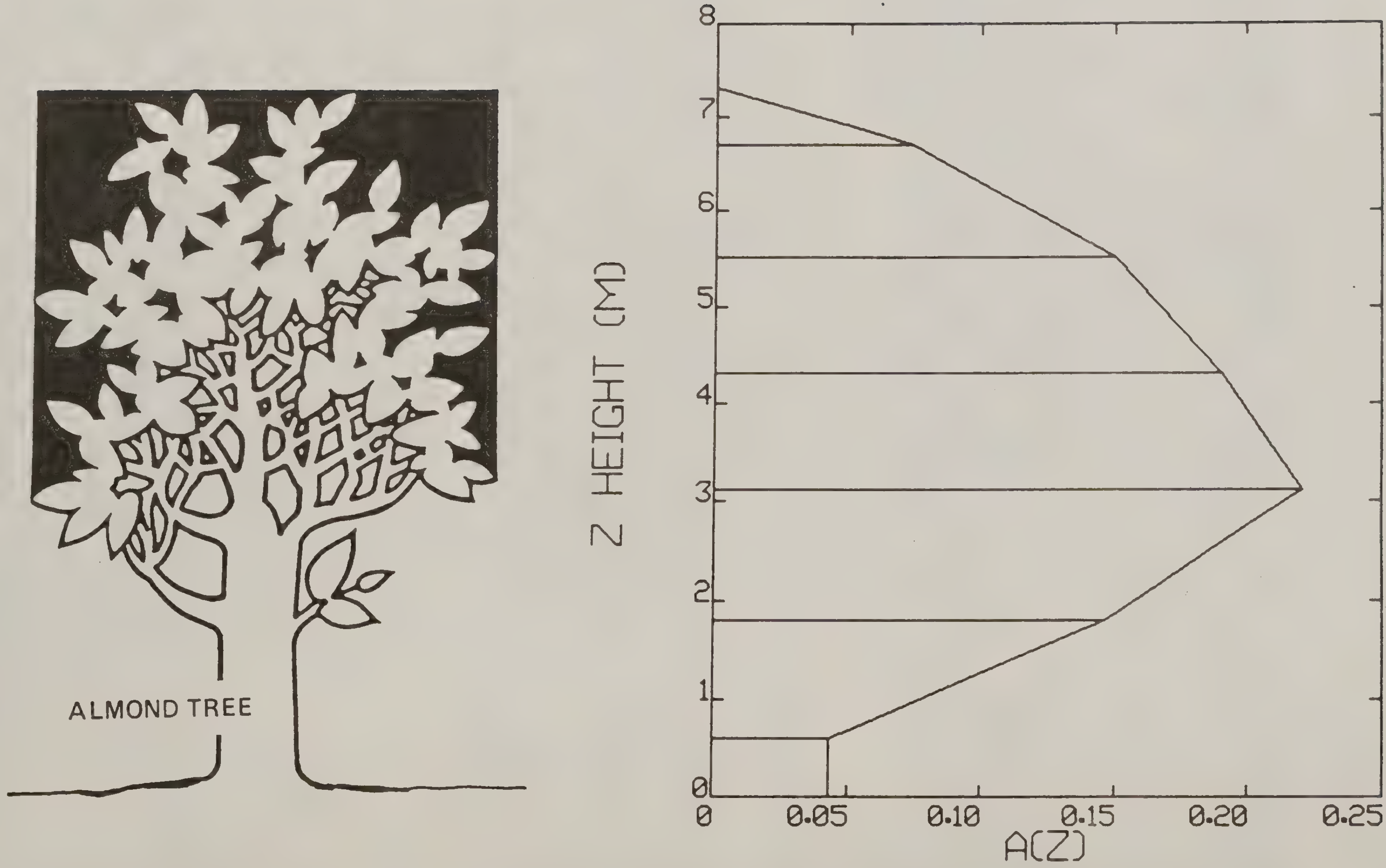



Figure 2-7. Plant area fraction as inferred from the Chico almond orchard data in Ref. 24.

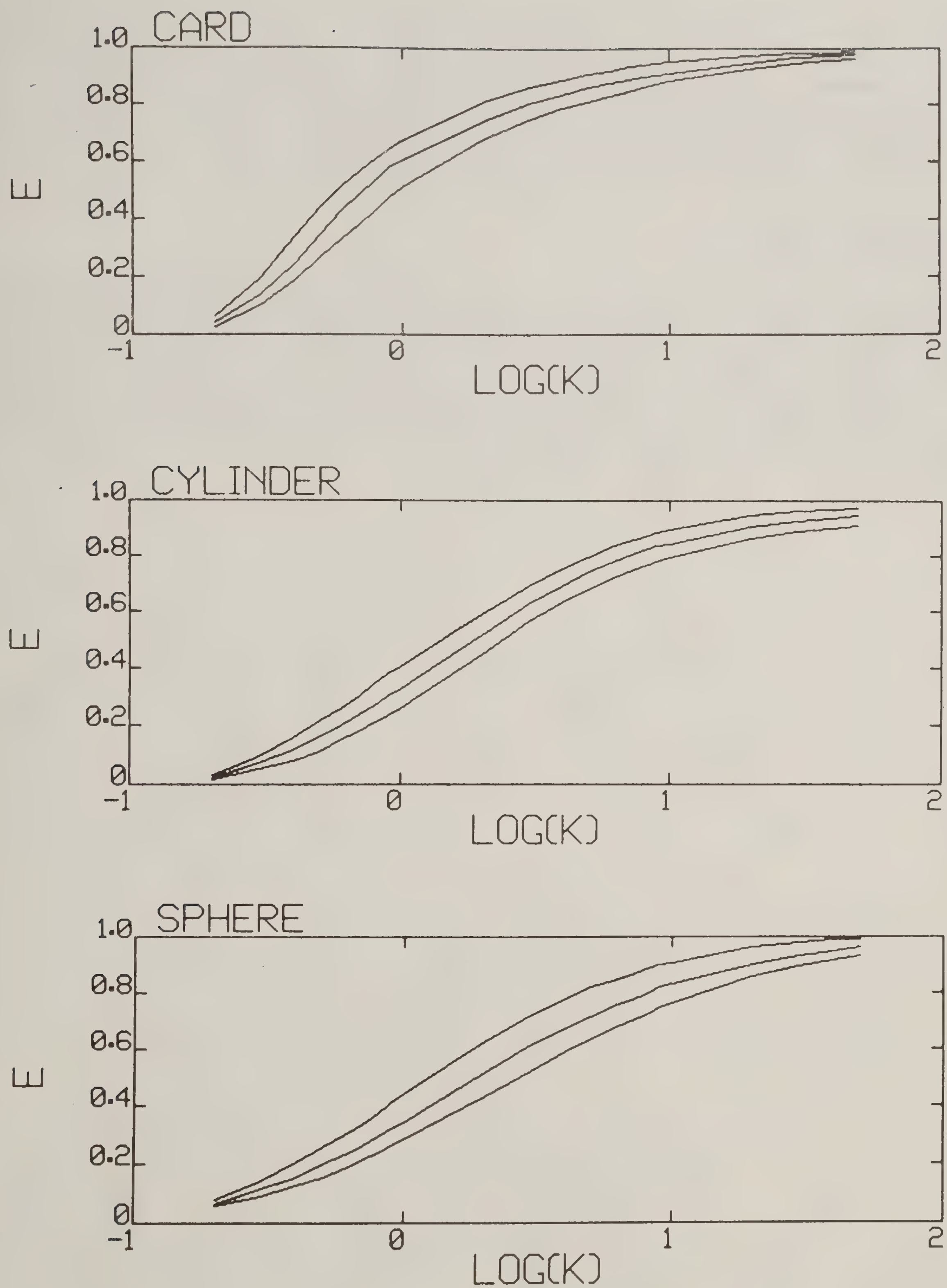



Figure 2-8. Inertial impaction efficiencies for targets discussed in Ref. 25. The top curve in each graph gives $\phi = 0$ ; the middle curve gives $\phi = 100$ ; and the bottom curve gives $\phi = 1000$ .

direction of a perpendicular line away from the target (in the case of a cylinder or a sphere this information isolates which half of the target is to be investigated). Some typical normal vectors are given in Figure 2-9. The effect of target orientation may be seen in Figure 2-10, where the deposition and target collection efficiency are plotted as functions of normal vector direction for a specific target location in Example Case 3.

## Overall Model Validation

The first significant comparison of the AGDISP code predictions with data was reported in Ref. 26, where the influence of fully rolled-up tip vortices, propeller and crosswind in the mean and variance equations were favorably compared with a series of fixed-wing experiments. Later detailed comparisons (Refs. 27-30) demonstrate the favorable performance of the AGDISP code when compared with detailed field test data for both fixed-wing and helicopter experiments over a wide material size range.

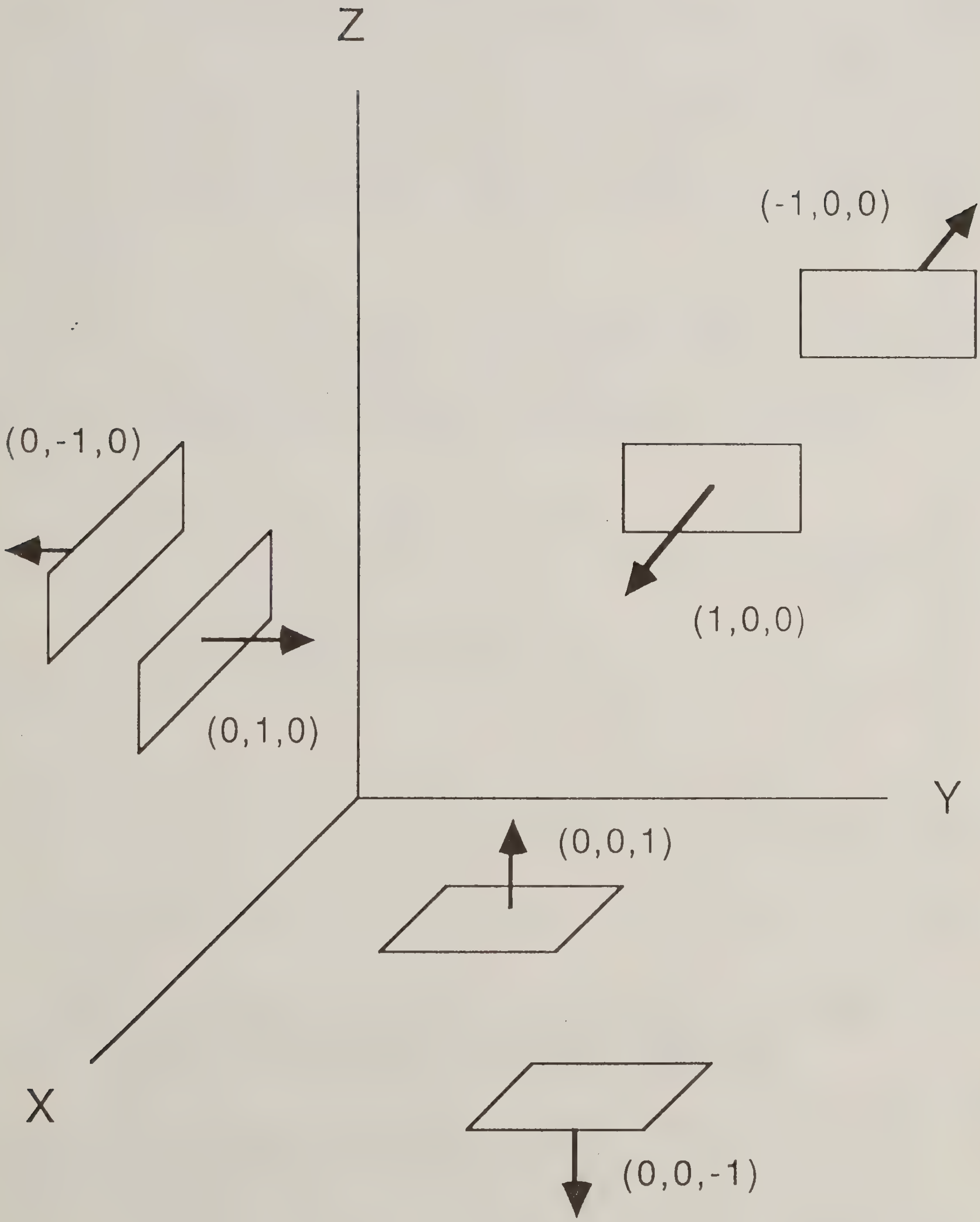



Figure 2-9. Typical target normal vectors given as (x,y,z) components.

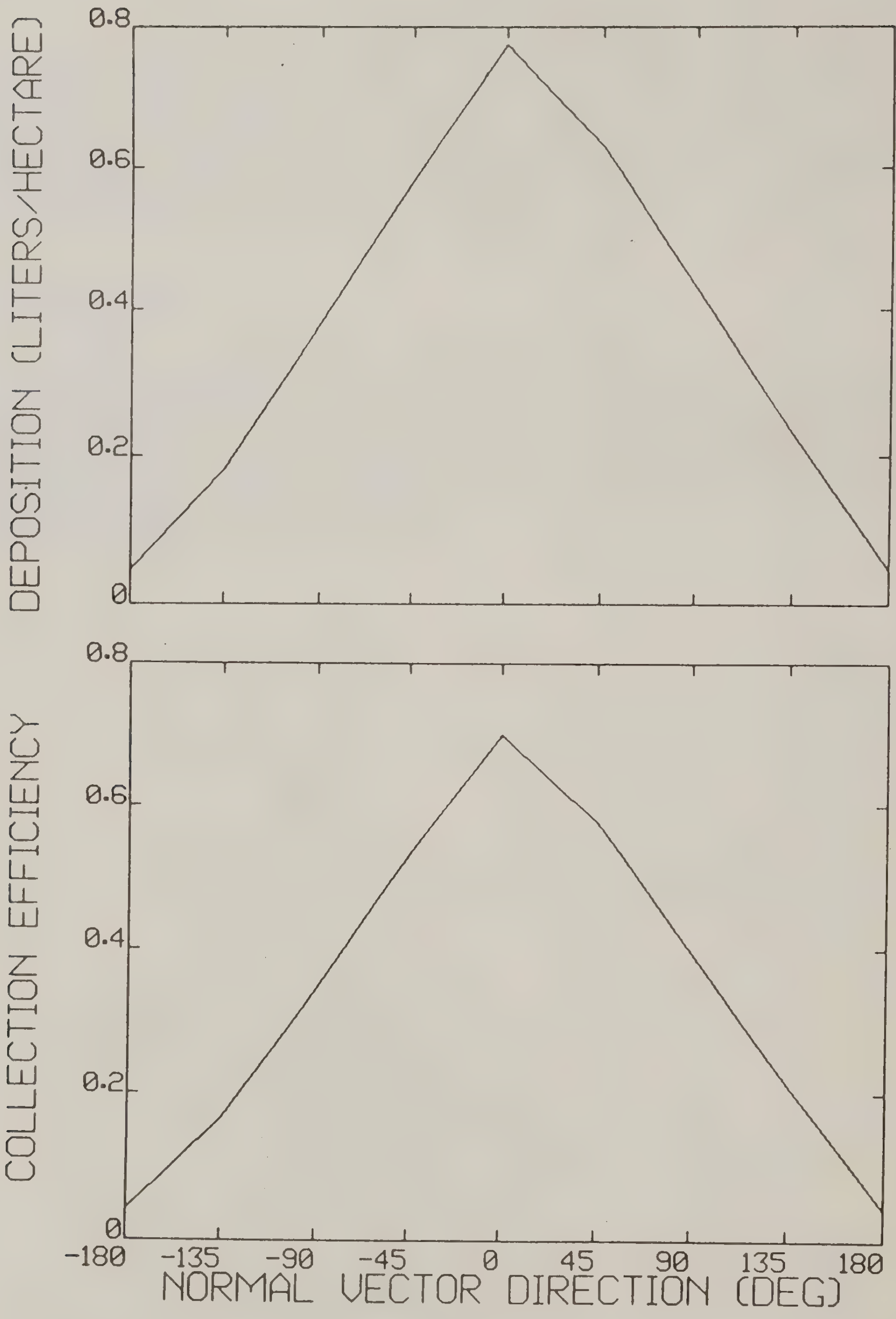



Figure 2-10. The deposition and target collection efficiency on a sphere of diameter 0.075m located in the wake of the AgTruck (Example Case 3) at y = -10m , z = 2m . All normal vectors are horizontal, with a direction of 0 degrees pointing in the -x direction (the flight direction of the aircraft); +90 degrees points in the +y direction; -90 degrees points in the -y direction; and ±180 degrees points in the +x direction (the wake of the aircraft).

# 3. CODE OPERATION

The AGDISP code consists of two programs: AGDISP for establishing the desired background fields and computing the material trajectories, and AGPLOT for plotting the resulting solutions. These programs are configured as interactive programs reading their needed input data from disk files and writing output to the terminal. Batch operation is discussed in Section 7. AGDISP reads an input file of data cards (valid cards are discussed in Section 4), types information to the terminal as the run proceeds, generates printed output in a separate file, stores material trajectory information in a plot file for subsequent plotting, and reads WAKE plot file results from a separate data file (if invoked). AGPLOT reads the desired material plot file and interactively questions the user to supply necessary scaling data for the plot construction.

The AGDISP code reads and processes the input data disk file, causing termination of the program if errors are discovered or needed cards are missing. Initialization follows: material locations and velocities, vortex strength, Betz roll-up, plant canopy, crosswind velocity profile, WAKE plot file. The material equations are then integrated repeatedly until one of three termination conditions occurs:

1. maximum simulation time is reached;

2. all of the released material has deposited on the surface; or

3. all of the material has reached the evaporation cutoff diameter and are removed from the calculation (if invoked).

Each integration step in turn includes the following:

1. equation system solution of the equations of motion;

2. updating the background mean velocity and turbulence fields by the WAKE plot file, Betz roll-up, vortex motion, or plant canopy; and

3. incremental file save of the results for subsequent plotting by AGPLOT.

At the end of a run, the surface impact statistics are summarized and the deposition fraction (the mass fraction of released material that has reached the surface in the desired simulation time) is computed.

AGDISP is run from and produces data into files assigned to specific unit numbers. These files are the following:

| UNIT | DESCRIPTION |
|---|---|
| 4 | AGDISP input file containing the appropriately constructed data entry cards. |
| 5 | Terminal input. |
| 6 | Terminal output. |
| 7 | CASEFILE default file set of AGDISP input files (accessed with input card 0005). |
| 8 | Binary file constructed by AGDISP and plotted by AGPLOT. |
| 9 | AGDISP printer listing file. |
| 10 | WAKE binary plot file. |
| 11-25 | Additional AGDISP binary plot files to be combined for composite deposition plots in AGPLOT. |

The current limits of the AGDISP code are the following:

1. All of the idealized background mean velocity and turbulence fields are for neutral environments. The inputted crosswind velocity profile will be interpreted as locally neutral.

2. The total number of nozzles that can be included in the simulation cannot exceed 60. The error message INCORRECT NUMBER OF DROPLETS will be invoked and AGDISP will terminate.

3. The Betz roll-up cannot enter more than 100 discrete circulation values along the wing. The error message ERROR IN CIRCULATION DATA INPUT will be invoked and AGDISP will terminate.

4. The Betz roll-up procedure cannot handle more than four discrete vortices rolling-up on each wing. In this case, the error message BETZ WILL ROLL-UP MORE THAN 4 VORTICES will be invoked and AGDISP will terminate.

5. The plant canopy input data cannot permit more than 20 discrete entries to define the canopy vertical profile shape. The error message ERROR IN PLANT AREA INPUT will be invoked and AGDISP will terminate.

6. The discrete crosswind velocity data cannot permit more than 20 entries to define the velocity profile. The error message ERROR IN CROSSWIND VELOCITY INPUT will be invoked and AGDISP will terminate.

7. The wide body data cannot permit more than 20 entries to define the fuselage cross-sectional area as a function of distance from the aircraft nose. The error message ERROR IN WIDE BODY AREA INPUT will be invoked and AGDISP will terminate.

8. The input deck to AGDISP cannot exceed 200 cards. The message AGDISP CONFIGURED FOR 200 INPUT CARDS will be invoked and AGDISP will terminate.

The complete alphabetized list of error messages generated in AGDISP are the following:

AGDISP CODE DOES NOT SUPPORT CARD
: the particular input card in question is not an allowable input card to AGDISP.

AGDISP CONFIGURED FOR 200 INPUT CARDS
: a maximum of 200 input cards are permitted in the AGDISP input deck.

BETZ WILL ROLL-UP MORE THAN 4 VORTICES
: a maximum of four vortices are permitted on a wing semispan.

CARD ORDER INCONSISTENT AT CARD
: input cards are not in increasing order, or an error in input has lead AGDISP to expect a card that is not in the input deck.

ERROR IN CIRCULATION DATA INPUT
: the Betz roll-up procedure must have between 3 and 100 discrete locations of circulation, with the last $y$ location entered as the negative of its actual value.

ERROR IN CROSSWIND VELOCITY INPUT
: the user-supplied crosswind velocity profile must have between 3 and 20 discrete locations of velocity, with the last $z$ height entered as the negative of its actual value.

ERROR IN PLANT AREA INPUT
: the plant canopy must have between 3 and 20 discrete locations of plant area fraction, with the last $z$ height entered as the negative of its actual value.

ERROR IN WIDE BODY AREA INPUT
: the wide body cross-sectional area must have between 3 and 20 discrete locations of area, with the last $x$ distance entered as the negative of its actual value.

FULL-PLANE CALCULATION REQUIRED
: Certain AGDISP options (terrain, propeller, crosswind, etc.) require that the solution be full-plane. If the user enters the half-plane flag on card 0010, AGDISP will terminate.

INCORRECT NUMBER OF DROPLETS
more than 60 nozzle locations are invoked in the simulation.

INITIAL CONDITION MISMATCH
Initial conditions were entered for a nozzle location that doesn't exist.

INPUT DOES NOT FULLY INITIALIZE AGDISP
input data cards are missing.

INSUFFICIENT DATA BEFORE CARD
the AGDISP run is not fully initialized; perhaps cards are missing from the input deck or a card does not have enough information on it.

INVALID CASE NUMBER
AGDISP could not locate the desired CASE number on card 0005 in the case file.

PREMATURE END OF WAKE PLOT FILE REACHED
the WAKE plot file ended without enough profile information.

WAKE PLOT FILE EXTRAPOLATION
Extrapolation of data in the WAKE plot file first occurs; this is a warning message.

WAKE PLOT FILE MESH SIZE
the WAKE plot file must have between 2 and 16 mesh points in the $y$ and $z$ directions.

The AGPLOT code interactively plots the AGDISP plot file contents on appropriate terminals or plotting devices. After scanning the file AGPLOT offers the current menu of plotting options available to the user (Section 5), who then determines the options to invoke. The list of error messages generated in AGPLOT are the following:

MAXIMUM SCALE LESS THAN MINIMUM SCALE
the user-supplied scale limits were inconsistent, and AGPLOT will request reentry of the scale data.

MAXIMUM SCALE SIZE ADJUSTED
the user-supplied scale limits were adjusted for consistency with the supplied scale delta.

NO EQUIVALENT GAUSSIAN CONSTRUCTED
there was no acceptable time at which an equivalent Gaussian could be constructed by AGPLOT.

OPTION NOT AVAILABLE FOR THIS DATAFILE
AGPLOT cannot invoke a requested option because the data is not available on the AGDISP plot file.

SCALE INCREMENT LESS THAN ZERO
the user-supplied scale increment was inconsistent, and AGPLOT will request reentry of the scale data.

TOO MANY SCALE DIVISIONS
the user-supplied scale data forced more than ten scale divisions, and AGPLOT will request reentry of the scale data.

TOTAL MASS FRACTION IS NOT 1.0
the user-supplied mass fractions do not add to one for the multiple plot files examined.

On the Data General, the following error messages are also possible:

GKS_DRAW ERROR
GKS_OPEN ERROR
GKS_Q_WS_WIN ERROR

GKS graphics errors on the Data General have occurred. These messages can only imply that something is significantly wrong with the program operation of AGPLOT.

# 4. AGDISP INPUTS

This section of the AGDISP User Manual details the input cards to the code. All data entry is in free format, with card data separated by commas or blank spaces. This convenience offers ease of formatting the data but requires that every data card have all of its data values present, even if they are zero. Unless noted below as integer values, data is entered as real numbers (with decimal points). The MKS system is used throughout.

All data cards begin with a four-digit identification in columns 1-4, with the rest of the data in free format after column 5. The order of the cards is important and must follow ever-increasing identification numbers. The AGDISP code has been programmed to verify this order. In addition, certain available options are inconsistent with each other. The AGDISP code has been programmed to trap these inconsistencies, with the message CARD ORDER INCONSISTENT AT CARD followed by the offending card when an error is detected. Unsupported cards are flagged with the message AGDISP CODE DOES NOT SUPPORT CARD, while missing data cards are flagged with INPUT DOES NOT FULLY INITIALIZE AGDISP. With free format there exists the chance that all necessary data does not appear on the appropriate card; in this case, the AGDISP code will run out of data cards before it rationalizes all of its data pointers. The error message will read INSUFFICIENT DATA BEFORE CARD following the card where data ended. The appearance of this error message may require a detailed examination of all data cards to determine the missing data. On the other hand, because all of the data is echoed on the terminal, error messages are traceable in a systematic manner. A careful check should be made the first time a new case is started, and at least until the user is confident of the program input requirements. Only by looking at what the program thinks is inputted will the user be able to verify that what was inputted was correct. In almost all cases, the code makes no check of input validity, either signs or magnitudes. The acceleration of gravity is built into the program as 9.8 m/sec$^2$ . Every AGDISP run requires the entry, at least, of cards 0010, 0020, 0050 and 0060. Table 4-1 summarizes all input cards.

Detailed description of the currently available data cards follows, including the special messages they invoke.

Caution: all input cards are described below, but for a specific AGDISP run, only those cards that are needed to describe the run should be included. Default entry (cards 0010, 0020, 0050 and 0060) will be sufficient to describe most runs. For example, if the run is made without evaporation, there is no reason to include card 0065.

0000 CMNT

| Variable | Type | Description (Comment Card) |
|---|---|---|
| CMNT | CHAR | Comment card, any number of which may be placed anywhere in the input deck. |

| Card | Contents | Required | Fixed-Wing | Helicopter | Ground Sprayer | Crosswind | Evaporation | Canopy | Terrain |
|---|---|---|---|---|---|---|---|---|---|
| 0000 | Comment | ○ | | | | | | | |
| 0005 | Casefile | ○ | | | | | | | |
| 0010 | Program | ● | | | | | | | |
| 0011 | Printer/Plotter Control | ○ | | | | | | | |
| 0015 | Terrain Slope Angle | | | | | | | | ● |
| 0020 | Aircraft Characteristics | ● | | | | | | | |
| 0021 | Biplane Characteristics | | ○ | | | | | | |
| 0023 | Aircraft Weight | | ◑ | | | | | | |
| 0025 | Betz Wing Load Distribution | | ◑ | | | | | | |
| 0028 | Neutral Crosswind | | | | | ◐ | | | |
| 0029 | Discrete Crosswind | | | | | ◐ | | | |
| 0030 | Helicopter | | | ● | | | | | |
| 0035 | Jet Engine | | ◓ | | | | | | |
| 0040 | Propeller | | ◓ | | | | | | |
| 0045 | Powerplant Placement | | ○ | | | | | | |
| 0050 | Turbulence | ● | | | | | | | |
| 0055 | Canopy | | | | | | | ● | |
| 0056 | Canopy Collection Efficiency | | | | | | | ○ | |
| 0060 | Nozzle | ● | | | | | | | |
| 0061 | Discrete Nozzle Location | | ○ | ○ | ● | | | | |
| 0062 | Nozzle Initial Condition | | ○ | ○ | ○ | | | | |
| 0065 | Evaporation | | | | | | ● | | |
| 0066 | Evaporation Parameterization | | | | | | ○ | | |
| 0070 | Apparent Surface Height | ○ | | | | | | | |
| 0075 | Circulation Decay | | ○ | ○ | | | | | |
| 0080 | Wide-Body Setup | | ○ | ○ | | | | | |
| 0081 | Wide-Body Effect | | ○ | ○ | | | | | |

● Card must be present in input deck

○ Card may be present in input deck

◑ ◐ ◓ Card pairs, one of which must be present if invoked

TABLE 4-1. AGDISP input card summary, broken into convenient categories for typical options. The "Required" cards are added with other option cards to build the complete input deck.

0005 ICASE

| Variable | Type | Description (Casefile Card) |
|---|---|---|
| ICASE | INT | Case to run (or modify) found in the default case input datafile. All of the input cards found on the case file for this case value will be added to the input runstream to build a complete input deck for AGDISP. Cards present in the input file will replace any cards of identical number found in the case file.<br><br>The case file may contain any number of input files to AGDISP, each with its input information consistent with the discussion in this section. The only attribute that separates the case file decks is a first card to each deck containing the word CASE in columns 1-4 and the case number beyond column 5. With card 0005 present, AGDISP will search the default case input datafile to find a match of case number; if that match is made, all of the subsequent cards up to the next CASE card will be copied to the input runstream. If a match is not made, AGDISP will print INVALID CASE NUMBER and terminate. |

0010 TMAX LHFPL

| Variable | Type | Description (Program Card) |
|---|---|---|
| TMAX | REAL | Maximum time in seconds for the simulation to run, a time which will be shortened if the material impacts the surface or is discarded at the evaporation cutoff before the maximum time is reached. |
| LHFPL | INT | Simulation plane entry configuring either a half-plane ($y > 0$) solution (a value of 1), or a full plane ($-\infty < y < +\infty$) solution (a value of 2). The full plane solution should be invoked if crosswind, propeller or terrain exist. |

0011 NPTJ NPVX NPVL NPXX

| Variable | Type | Description (Printer/Plotter Control Card) |
|---|---|---|
| NPTJ | INT | Modified default printing interval. Under normal operation AGDISP output is generated at appropriate intervals to the printer and the plot file. Entry of a number greater than 1 increases the printing interval (the plotting interval cannot be altered). Default value is 1; to turn off printing requires an entry of 0. |

| | | |
|---|---|---|
| NPVX | INT | Invokes plot file saving of the time histories of the driving trajectories, and controls the interval of printing these time histories. The driving trajectories are those associated with the centers of vortices, the center of the propeller and the center of the helicopter rotor disk (whenever any are present in a particular run). Any value for this entry invokes additional plot file output, to permit subsequent plotting of the driving trajectories by AGPLOT. A number greater than 1 increases the printing interval. Default value is 0. |
| NPVL | INT | Controls whether the vertical velocities are saved on the plot file for subsequent plotting by AGPLOT. Default value is 0 (no saving of vertical velocities); any nonzero value entered on this card will force additional plot file output. Vertical velocities must be saved if the AGPLOT option for the equivalent Gaussian distribution is to be invoked. |
| NPXX | INT | Controls whether the mean velocities are saved on the plot file for subsequent plotting by AGPLOT. Default value is 0 (no saving of mean velocities); any nonzero value entered on this card will force additional plot file output. Mean velocities must be saved if the AGPLOT option for deposition on objects is to be invoked. |

In all cases, additional writes to the plot file will increase its size.

0015 TA

| Variable | Type | Description (Terrain Slope Angle Card) |
|---|---|---|
| TA | REAL | Local ground slope in degrees. A positive terrain angle raises the right side of the surface as viewed from behind the aircraft, with the origin remaining along the initial aircraft vertical centerline. The terrain is characterized by a locally straight surface so that all of the simplified flow field options in AGDISP remain available. A full plane solution is necessary. Canopy and crosswind effects remain parallel to the tilted surface. |

0020 LMVEL S DIST UO

| Variable | Type | Description (Aircraft Characteristics Card) |
|---|---|---|
| LMVEL | INT | Mean velocity flag taking one of seven values:<br>5 denotes ground sprayer;<br>4 denotes helicopter entry;<br>3 denotes an elliptically loaded, fully rolled-up tip vortex;<br>2 denotes a rectangularly loaded, fully rolled-up tip vortex;<br>1 denotes a triangularly loaded, fully rolled-up tip vortex;<br>0 denotes Betz roll-up from a given circulation, and<br>-1 denotes WAKE plot file entry (explained under card 0050).<br><br>An entry of 4 requires a 0030 card; entry of 3, 2 or 1 requires a 0023 card; and an entry of 0 requires multiple entries of 0025 cards. |
| S | REAL | Semispan of the aircraft in meters (also the rotor radius for a helicopter). |
| DIST | REAL | Nominal height of the aircraft wing about the surface in meters (this distance is the assumed nominal nozzle release height). For fully rolled-up tip vortices, this height is the initial $z$ coordinate of the vortex centerline. For Betz roll-up data this height is the $z$ coordinate of the initial vortex sheet (assumed horizontal). |
| UO | REAL | Flight speed of the aircraft in m/sec. |

0021 DZBP PSBP PGBP

| Variable | Type | Description (Biplane Characteristics Card) |
|---|---|---|
| DZBP | REAL | Vertical distance in meters from the main wing location specified on card 0020 to the biplane wing. |
| PSBP | REAL | Semispan of the biplane wing entered as a fraction of the semispan of the main wing (if the wings are equal in length this entry would be 1.0). |
| PGBP | REAL | Weight carried by the biplane wing entered as a fraction of the weight carried by the main wing (for equal weights this entry would be 1.0). |

0023 WT

| Variable | Type | Description (Aircraft Weight Card) |
|---|---|---|
| WT | REAL | Weight of the fixed-wing aircraft in N , for a fully rolled-up tip vortex pair. |

0025 Y G

| Variable | Type | Description (Betz Wing Load Distribution Cards) |
|---|---|---|
| Y | REAL | Position in meters measured from the wing root monotonically towards the tip. |
| G | REAL | Circulation value in $m^2$/sec at this location. |

The final card is signaled by entering the last y position as the negative of its actual value. This card then forces initialization of the Betz roll-up procedure. This initialization (and the ensuing roll-up) invoke extra printer output summarizing the roll-up process.

As the Betz roll-up continues, the material being tracked will be influenced by ever-increasing strength vortices, whose positions and strengths will approach those of fully rolled-up vortices. The AGDISP code includes the effect of the unrolled-up sheets on the motion of the released material.

0028 U Z ZO CA

| Variable | Type | Description (Neutral Crosswind Card) |
|---|---|---|
| U | REAL | Mean wind velocity in the (x,y) plane in m/sec. |
| Z | REAL | Altitude of the mean wind velocity in meters. |
| ZO | REAL | Surface roughness height $z_o$ in meters. |
| CA | REAL | Direction angle in degrees from which the wind is blowing, i.e., for 0° the wind is a head wind; for 180° the wind is a tail wind; for 90° the wind is a crosswind from right to left; and for -90° (or 270°) the wind is a crosswind from left to right. |

0029 Z U V

| Variable | Type | Description (Discrete Crosswind Cards) |
|---|---|---|
| Z | REAL | Position in meters beginning at the surface and increasing monotonically to the top of the computational domain. |
| U | REAL | Axial velocity value in m/sec, positive pointing downstream (headwind). |
| V | REAL | Crosswind velocity value in m/sec positive pointing in the positive y direction. The square root of the sum of the squares of U and V recovers the total velocity magnitude at height z . |

The final card is signaled by entering the last z position as the negative of its actual value. This card entry then initializes a calculation of the turbulence level throughout the velocity profile. If a canopy is present, it is assumed that the entries on cards 0029 have been modified by the user of AGDISP to reflect the influence of the canopy on the crosswind velocity profile and the subsequent turbulence calculation.

0030 WT BDOT

| Variable | Type | Description (Helicopter Card) |
|---|---|---|
| WT | REAL | Weight of the helicopter in N . |
| BDOT | REAL | Blade rotation rate in rpm. |

The helicopter is idealized as a dynamic transition from a rotor downwash field to a rectangularly loaded, fully rolled-up vortex pair.

0035 THT RPRP DZ XPRP

| Variable | Type | Description (Jet Engine Card) |
|---|---|---|
| THT | REAL | Thrust of the engine in N . |
| RPRP | REAL | Exit radius of the engine in meters. |
| DZ | REAL | Incremental distance in meters of the engine centerline above or below the nominal release height given on card 0020 (the jet engine is assumed to be at the airplane centerline, y = 0). The placement of |

the jet engine is superceded by the presence of card 0045.

| | | |
|---|---|---|
| XPRP | REAL | Axial distance from the trailing edge of the wing to the exit plane of the jet engine in meters, where positive is downstream. |

0040 CD AS ETA TDOT RPRP DZ XPRP

| Variable | Type | Description (Propeller Card) |
|---|---|---|
| CD | REAL | Drag coefficient of the aircraft. |
| AS | REAL | Airplane planform area in $m^2$. |
| ETA | REAL | Propeller efficiency. |
| TDOT | REAL | Shaft rpm. |
| RPRP | REAL | Propeller blade radius in meters. |
| DZ | REAL | Incremental distance in meters of the shaft centerline above or below the nominal release height given on card 0020 (the propeller is assumed to be at the airplane centerline, y = 0). The placement of the propeller is superceded by the presence of card 0045. |
| XPRP | REAL | Axial distance from the trailing edge of the wing to the propeller blade plane in meters, where positive is downstream. |

0045 NPRP (TV(N), N = 1 TO NPRP)

| Variable | Type | Description (Powerplant Placement Card) |
|---|---|---|
| NPRP | INT | Number of engines (1 to 4, although 1 is the default on cards 0035 and 0040). |
| TV | REAL | An equal number of dimensions following the pattern |

for one engine:
incremental distance (meters) at the aircraft centerline above or below the nominal height.

for two engines:
positive horizontal position (meters) of the engine from the aircraft centerline; and
incremental distance (meters) of the engine above or below the nominal height (the other engine is symmetrically positioned);

for three engines:

incremental distance (meters) at the aircraft centerline above or below the nominal height for the engine at the aircraft centerline;
positive horizontal position (meters) of the second engine from the aircraft centerline; and
incremental distance (meters) of the second engine above or below the nominal height (the third engine is symmetrically positioned);

for four engines:

positive horizontal position (meters) of the first engine from the aircraft centerline;
incremental distance (meters) of the first engine above or below the nominal height (the second engine is symmetrically positioned);
positive horizontal position (meters) of the third engine from the aircraft centerline; and
incremental distance (meters) of the third engine above or below the nominal height (the fourth engine is symmetrically positioned).

0050 LQQSE QQMX

| Variable | Type | Description (Turbulence Card) |
|---|---|---|
| LQQSE | INT | Turbulence flag carrying one of the following values:<br><br>1 invokes superequilibrium turbulence;<br>0 assumes a fixed value of turbulence given on this card; and<br>-1 specified the attached WAKE plot file (invoked with a -1 entry on card 0020). |
| QQMX | REAL | Maximum value of the background turbulence $q^2$ in $m^2/sec^2$ (this value is incremented by the presence of a crosswind). The turbulence level generated by a crosswind flowfield is generally sufficient to represent the ambient turbulence level (the input on card 0050 would then be 0.0 for $q^2$). However, in some cases, it may be necessary to augment this value for specific local atmospheric conditions. A short guide to the selection of appropriate background turbulence levels is offered in Section 8.<br><br>A -1 on card 0020 invokes the WAKE plot file and must be accompanied by a -1 on this card. The WAKE plot file contains the crossplane velocities V and W , and the turbulence $q^2$ . |

The sequential binary WAKE plot file is constructed as follows:

record 1: the number of $y$ (or horizontal) mesh points and $z$ (or vertical) mesh points in the plot file (two integers). The code restricts both of these entries to 16 or less; larger values invoke WAKE PLOT FILE MESH SIZE;

record 2: the $y$ mesh values in meters;

record 3: the $z$ mesh values in meters;

record 4 and following: the profile data follows, with each time slot repeating the same pattern. It begins with a single record which is the time saved in seconds. The data for each variable on the file (specified in the order $V, W, q^2$ ) follows, by giving all of the $y$ values of $V$ at the first $z$ position, then all of the $y$ values of $V$ at the second $z$ position, on to the last $z$ position; then on to all of the $y$ values of $W$ at the first $z$ position, etc., until the values of all of the variables at all of the $y$ and $z$ positions have been given. The next time value follows, repeated to the end of the plot file. Velocities are in m/sec and turbulence in $m^2/sec^2$ . The warning message WAKE PLOT FILE EXTRAPOLATION is output the first time spatial extrapolation must be used by the AGDISP code during interpolation for the variables contained on the WAKE plot file. For times beyond the entries in the WAKE plot file, the spatial profiles nearest in time to the time being solved in AGDISP will be used.

Before integrating the equations, AGDISP reads the entire WAKE plot file through to its end. If the file is constructed incorrectly, the error message PREMATURE END OF WAKE PLOT FILE REACHED is invoked, and AGDISP terminates.

0055 Z AA

| Variable | Type | Description (Canopy Cards) |
|---|---|---|
| Z | REAL | Position in meters beginning at the surface and increasing monotonically to the top of the canopy. |
| AA | REAL | Plant area fraction corresponding to the $z$ position. |
| | | The final card 0055 is signaled by entering the last $z$ position as the negative of its actual value. This |

card entry then initializes the canopy calculation, computing the displacement thickness of the canopy and forcing modification to the crosswind velocity and turbulence within the canopy. During the AGDISP run, the trajectories of the aircraft vortices will be altered upon entering the canopy, and the position of the helicopter dividing streamline will be changed.

0056 CEFF

| Variable | Type | Description (Canopy Collection Efficiency Card) |
|---|---|---|
| CEFF | REAL | Canopy capture efficiency $\beta$ . Default value is 1.0. |

0060 LPART LZERO DZ XO DIAM DENF

| Variable | Type | Description (Nozzle Card) |
|---|---|---|
| LPART | INT | Number of nozzles in the half-plane $(y > 0)$ . |
| LZERO | INT | Centerline nozzle flag: equal to 1 if a nozzle is positioned at the centerline of the aircraft $(y = 0)$; otherwise it is equal to 0.<br><br>A half-plane solution will track total released material equal to the sum of these two integers; a full-plane solution will track total released material equal to the sum of twice the first integer plus the second integer. Additionally, if these two integers are entered positive, AGDISP will position the nozzles uniformly along the wing (for a first integer entry of 1, the nozzle will be positioned at 1/2 the semispan; for a first integer entry of 2, the nozzles will be positioned at 1/3 and 2/3 the semispan, etc.). If these two integers are entered negative, AGDISP will expect sufficient 0061 cards in the input deck to initialize all of the nozzles. |
| DZ | REAL | Vertical position in meters off-setting the material release point from the height of the wing given on card 0020. |
| XO | REAL | Nominal axial position of the nozzles relative to the trailing edge of the wing (or the shaft centerline of the helicopter) in meters, positive measured downstream. |
| DIAM | REAL | Diameter in microns of the released material (only one size may be released during any one AGDISP run). |

| | | |
|---|---|---|
| DENF | REAL | Specific gravity of the released material. |

0061 Y Z

| Variable | Type | Description (Discrete Nozzle Location Cards) |
|---|---|---|
| Y | REAL | Y value in meters along the spray boom. |
| Z | REAL | Vertical position in meters off-setting the release point from the height of the wing given on card 0020. The vertical position off-set on card 0060 is disregarded. Discrete nozzle locations allow for fine tuning of nozzle locations, and are necessary if nozzles are not uniformly distributed along the wing or if the spray boom is not parallel to the surface.<br><br>There must be enough 0061 cards to satisfy the requirements of the 0060 card. If a full-plane solution is invoked <u>all</u> nozzle locations must be specified. If a nozzle is located along the centerline in a half-plane simulation, that nozzle must be the <u>last</u> card 0061 for purposes of computing the ground deposition correctly. |

0062 N U V W XS VS

| Variable | Type | Description (Nozzle Initial Condition Cards) |
|---|---|---|
| N | INT | Nozzle number, recorded from the left most nozzle position. |
| U | REAL | Initial axial velocity in m/sec at nozzle N , positive measured downstream. |
| V | REAL | Initial horizontal velocity in m/sec at nozzle N . |
| W | REAL | Initial vertical velocity in m/sec at nozzle N . |
| XS | REAL | Initial spatial variance of the material path in $m^2$ at nozzle N . |
| VS | REAL | Initial velocity variance of the material in $m^2/sec^2$ at nozzle N .<br><br>All initial conditions are set to zero unless modified by card 0062 for each nozzle. Card 0062 is ideal for configurations with few nozzles, such as ground sprayers. |

0065 DTEMP DCUT

| Variable | Type | Description (Evaporation Card) |
|---|---|---|
| DTEMP | REAL | Wet bulb temperature difference in deg C. |
| DCUT | REAL | Material diameter in microns below which evaporation ceases (the cut-off diameter). |

If the wet bulb temperature difference entered on this card is zero, AGDISP assumes that evaporation will be parameterized, and expects card 0066. If DCUT is negative, material is removed from the simulation when it evaporates down to the absolute value of DCUT.

0066 DEA DEB DEC

| Variable | Type | Description (Evaporation Parameterization Card) |
|---|---|---|
| DEA | REAL | Coefficient A in microns in the material diameter equation |

$$\text{Diameter} = A + Bt + Ct^2 \qquad (50)$$

| Variable | Type | Description |
|---|---|---|
| DEB | REAL | Coefficient B in microns/sec. |
| DEC | REAL | Coefficient C in microns/sec$^2$. |

These coefficients are compatible with the evaporation model in FSCBG (Ref. 31), and produce consistent evaporation results between AGDISP and FSCBG. The coefficient A should be identical to the material diameter entered on card 0060.

0070 Z

| Variable | Type | Description (Apparent Surface Height Card) |
|---|---|---|
| Z | REAL | Apparent height above the surface (in meters) at which the material deposits. The default condition requires impact of material at the surface (with an apparent height equal to zero). For a nonzero entry, when material intersects the apparent height, it is removed from the computation, just as though it had impacted the surface. A subsequent ground deposition plot with AGPLOT will recover the deposition of the material at the apparent height entered on this card. |

0075 GDK

| Variable | Type | Description (Circulation Decay Card) |
| --- | --- | --- |
| GDK | REAL | Factor (nondimensional) that forces a time reduction in the circulation strength of the vortices. Default value is zero (no decay). If this entry is negative, its absolute value is taken as the circulation decay constant multiplied by the ambient turbulence level. Reference 14 suggests that for small material sizes, an appropriate entry on card 0075 is -0.56 m/sec. |

0080 XBOD DZ

| Variable | Type | Description (Wide-Body Setup Card) |
| --- | --- | --- |
| XBOD | REAL | Position in meters of the front of the fuselage from the trailing edge of the wing (or the shaft centerline of the helicopter), positive measured downstream (by convention, then, this number must be negative). |
| DZ | REAL | Vertical distance in meters off-setting the nose centerline of the fuselage from the nominal height of the wing (or rotor plane) given on card 0020. The fuselage is assumed to be axisymmetric. If card 0080 is present, cards 0081 must also be present to define the fuselage body shape. |

0081 X SS

| Variable | Type | Description (Wide-Body Effect Cards) |
| --- | --- | --- |
| X | REAL | Position in meters, measured positive from the nose of the fuselage to the tail, increasing monotonically. |
| SS | REAL | Cross-sectional area of the fuselage in $m^2$, corresponding to the x position. |

The first 0081 card must contain 0.0 for x and 0.0 for the area. The final card is signaled by entering the last x position as the negative of the actual fuselage body length, with the corresponding area as 0.0. This card entry initializes the wide body effects of a source-sink velocity profile near the fuselage and an axisymmetric turbulent wake decaying behind the fuselage.

# 5. AGPLOT INPUTS

The AGPLOT program may be invoked to plot the resulting trajectories and deposition pattern from an AGDISP run or multiple AGDISP runs. The code asks questions of the user in the interactive environment, and with this information processes the data and plots the results.

At the beginning of AGPLOT, the data file is read, the input data deck used to generate the file is written to the screen (to serve as verification of the proper run to plot), and the file is scanned for maximum values and available options. With this information in hand, AGPLOT will display its current menu driver:

```
 0  EXIT AGPLOT
 1  MEAN DROPLET TRAJECTORIES
 2  MEAN + STANDARD DEVIATION TRAJECTORIES
 3  VORTICES/HELICOPTER/ENGINE CENTROIDS
 4  GAUSSIAN GROUND DEPOSITION
 5  CONTINUOUS GROUND DEPOSITION
 6  CANOPY DEPOSITION
 7  TOTAL CANOPY DEPOSITION
 8  EQUIVALENT GAUSSIAN DISTRIBUTION
 9  CROSSWIND VELOCITY PROFILE
10  CANOPY PLANT AREA FRACTION PROFILE
11  DROPLET DIAMETER TIME HISTORY
12  DROPLET CANOPY PARAMETER TIME HISTORY
13  DROPLET AXIAL VELOCITY TIME HISTORY
14  DROPLET HORIZONTAL VELOCITY TIME HISTORY
15  DROPLET VERTICAL VELOCITY TIME HISTORY
16  OBJECT DEPOSITION TIME HISTORY
17  DRIFT FRACTION TIME HISTORY
```

followed by the request ENTER OPTION TO RUN. Only those options available from the data in the plot file will be displayed. Each of the options is described as follows:

0 is entered to exit from AGPLOT. Since several menu options may be invoked for one AGDISP run, 0 is the entry used to complete the plotting for a particular plot file.

1 is entered to plot the mean trajectories.

2 is entered to plot the mean trajectories (as solid curves) and the standard deviation of the trajectories (as dashed curves).

3 is entered to plot the trajectories of the vortex centroids (as solid curves) and the center(s) of the propeller, jet engine or helicopter (as a dashed curve), if applicable. This option is available only with an appropriate nonzero entry on card 0011.

4 is entered to compute and plot the composite ground deposition pattern for the current plot file and for additional plot files (up to a total of 16 plot files) established by the user and accessed with unit numbers of 11 and higher. The user must decide the appropriate mass fractions for each of the runs to be combined. Since the current plot file is already in place, AGPLOT will request ENTER CURRENT FILE MASS FRACTION. After this AGPLOT will open unit 11 and request ENTER MASS FRACTION for the next plot file. Further plot files will be expected sequentially on units 12, 13, 14, etc. A total mass fraction of unity will terminate the requests. If the total mass fraction is not close to unity, the warning message TOTAL MASS FRACTION IS NOT 1.0 will appear. AGPLOT will represent all of the impacted particles as Gaussian distributions, following Eq. (45). Six different deposition scales are available in AGPLOT. These scales require the mass flow rate per nozzle, and so AGPLOT requests ENTER GALLONS/MINUTE/NOZZLE to properly compute the deposition. These six scales are: NORMALIZED,LITERS/HECTARE, OUNCES/ACRE, GALLONS/ACRE, MG/M**2 and DROPS/CM**2. AGPLOT requests ENTER SCALE TO USE. An integral under the deposition curve will reflect the number and mass of material that have impacted the surface. This number appears in a corner of the plot.

5 is entered to compute and plot the composite ground deposition pattern as for option 4 but with continuous deposition following Eq. (46).

6 is entered to compute and plot contours of the composite canopy deposition pattern following incremental Gaussian deposition through the canopy. Up to a total of 16 plots files may be combined in one contour plot, with the procedure similar to option 4. Here, however, the droplet canopy parameter defined in Eq. (47) is summed to accumulate deposition in specified layers through the canopy. The user is then quizzed to give specific contour values to be plotted. Option 6 must be exercised to generate the profile distribution needed for option 7. Contour values appear in a corner of the plot.

7 is entered to plot the total canopy deposition.

8 is entered to compute and display the equivalent Gaussian distribution. Since the position and standard deviation of all material in the simulation is computed by AGDISP as a function of time after release, the equivalent mean position and standard deviation may be determined by appropriate summation and integration at each time over all material in the simulation. A measure of the compatibility of the equivalent Gaussian distribution is made by computing a figure of merit ranging from 0 to 1. When the equivalent Gaussian no where represents the multiple-particle distribution, the figure of merit equals zero. When the equivalent Gaussian is every where identical to

the multiple distribution, the figure of merit is unity. Equivalent Gaussian calculations are made for every time on the plot file, with all times given a monotonically increasing sequence number. The critical sequence numbers, the time associated with each of them, and their respective figure of merit and terminal velocity criterion are typed to the screen whenever: the first sequence number is reached; the last sequence number is reached; the figure of merit reaches a local minimum; the figure of merit reaches a local maximum; or material first comes within a standard deviation of the ground.

The terminal velocity for the material size examined is computed assuming no evaporative effects and a specific gravity of unity. It is displayed with the message TERMINAL VELOCITY as reference to the user. The terminal velocity criterion is computed as the average over all material of their vertical velocities relative to their terminal velocity (if all material were moving at their terminal velocity, the WCRIT value would be one). Option 8 requires that the particle vertical velocity be saved on the plot file by the appropriate input on card 0011 in AGDISP. Material whose vertical velocities are not within fifty percent of their terminal velocity will not contribute to the figure of merit calculations at that time step.

After processing the entire plot file and displaying the above summary information, the plot file is reread to locate the position of maximum figure of merit. At this point, the equivalent Gaussian data is displayed on the screen. If the equivalent Gaussian vertical standard deviation contacts the surface, the warning message GROUND ENCOUNTER BY EQUIVALENT GAUSSIAN will be displayed on the screen. Material that does not contribute to the equivalent Gaussian distribution (because it is trapped by vortex flow in the aircraft wake, or because it has come within a standard deviation of the surface) will be noted by the **TRAPPED** comment. If none of the material in the simulation qualify for contribution to the equivalent Gaussian, the message NO EQUIVALENT GAUSSIAN CONSTRUCTED will be displayed, and the subsequent plot will be skipped.

The resulting plot represents each released material distribution as dashed curves and the single equivalent Gaussian distribution as solid curves. Around each center point of the material contributing to the equivalent Gaussian, normalized contour lines are plotted at one-fourth and one times the standard deviation. Material not contributing to the equivalent Gaussian are plotted with much smaller ellipses to aid in identifying them. The plotted figure of merit appears in a corner of the plot.

9 is entered to plot the crosswind velocity profile (if available with a 0028 card or 0029 cards).

10 is entered to plot the canopy plant area fraction profile (if available with 0055 cards).

11 is entered to plot the time history of a droplet diameter (if evaporation is occurring). If there are more than one droplet in the simulation, AGPLOT will request ENTER DROPLET TO PROCESS.

12 is entered to plot the time history of the canopy deposition of a droplet (if canopy cards 0055 are present).

13 is entered to plot the time history of the axial U velocity of a droplet (if the mean velocity data is stored on the plot file with card 0011 in AGDISP).

14 is entered to plot the time history of the horizontal V velocity of a droplet (if the mean velocity data is stored on the plot file with card 0011 in AGDISP).

15 is entered to plot the time history of the vertical W velocity of a droplet (if the mean velocity data is stored on the plot file with card 0011 in AGDISP).

16 is entered to compute the time history of the deposition on a specified collector geometry at a specified position in the AGDISP solution field (the mean velocity data must be stored on the plot file with card 0011 in AGDISP).

The collector must first be placed in the solution field by responding to the request ENTER (Y,Z) COLLECTOR LOCATION with the y and z values in meters. Next, AGPLOT asks for the type of collector; currently, the options are card, cylinder or sphere. Then AGPLOT requests ENTER SIGNIFICANT TARGET DIMENSION to give a typical length in meters of the collector. Finally, AGPLOT needs to know the orientation of the collector relative to the (x,y,z) coordinate system, asking ENTER (X,Y,Z) NORMAL VECTOR. Here all three components must be entered; AGDISP will renormalize into a unit vector. A preferred normal direction must be supplied, even for collectors that do not appear to have planar geometry. If the collector were placed parallel to the surface, the normal vector would be (0,0,1). If the collector were vertical and deposition on the left side were needed, the normal vector would be (0,-1,0).

As with other deposition options, up to 16 plot files may be combined to compute the collector deposition. The total collection efficiency appears in a corner of the plot.

17 is entered to compute the time history of the drift of all of the droplets in the simulation (up to 16 plot files collected together).

Where appropriate, the following additional requests will be made:

FULL PLANE PLOT is asked whenever the AGDISP run is a half-plane run. Response in Y or N for yes or no, respectively.

AUTOSCALE AXES will compute appropriate plotting scales if invoked. If N is the response, AGPLOT will ask for Y SCALE MIN, MAX, INCR and Z SCALE MIN, MAX, INCR. AGPLOT has a scale checking routine and will invoke a warning message whenever the scale delta is not an integer fraction of the overall scale size. Additionally, three errors will be trapped: MAX SCALE LESS THAN MIN SCALE; SCALE INCR LESS THAN ZERO; and TOO MANY SCALE DIVISIONS whenever more than ten scale divisions are needed.

AUTOSCALE GRID will compute appropriate deposition intervals, if invoked, for options 5 and 6. If N is the response, AGPLOT will ask for Y SCALE MIN,MAX.

AUTOSCALE CONTOURS will contour plot appropriate deposition levels through the canopy in option 6. If N is the response, AGPLOT will ask for contour levels (and will plot them) until a negative deposition value is entered.

TAG LOCATION AT TIME INCREMENTS is asked for mean trajectories, to tag released material positions on the plot as a function of time. The size of the tag is scaled to the size of the material standard deviation. If the response is Y, AGPLOT will ask ENTER TAG TIME INCREMENT to enter the incremental seconds between tags.

ENTER PLOT TITLE is asked to enter the title of the current plot.

On the Data General the following additional messages are possible:

ENTER MASTER FILENAME
The filename containing the data to be manipulated (8 characters or less <u>without</u> extension) is entered here.

ENTER METAFILE.EXT FOR THIS PLOT
If metafiles are open (from a previous query), then each plot must be assigned a name and extension for storing on the DG system in the user directory. A metafile extension of GKM is recommended for entry into CEO.

ENTER PLOT SCALING FACTOR
Typically, all plots produced by AGPLOT will fill to the size available in the device. By entering a number here less than one, the plot will be scaled accordingly.

ENTER QUE NAME CODE
A hardcopy unit must be further specified by its queue name within the DG environment.

ENTER WORKSTATION TYPE
Response to this query will determine the plotting device to be used. If the first character of the response is not "D" or "d", AGPLOT assumes the device is a hardcopy unit and will request its QUE NAME.

OPEN OUTPUT METAFILES

While working with any graphics device, the resulting plots may also be spooled to a file for later manipulation. This option permits that operation.

PLOT COMPLETED: PRESS *RETURN* TO CONTINUE

The DG system will blank the screen after completing a plot unless a pause is programmed into AGPLOT.

Additionally, on the DG system, the pressing of any function key at a query line will return the user to the menu driver.

# 6. TEST CASES

Four test cases are included in the User Manual to illustrate the variety of data entry available with AGDISP. These examples are included to demonstrate the structure of the input card deck and the data entry requirements of each type of data card and option. They are not meant to suggest that certain options go with certain other options, nor are all options covered.

The four examples illustrate the following features:

1. The first test case examines the wake behind a F-15 fighter flying at Mach 0.5. Because of the high speed, the Betz roll-up is invoked, with a wing load distribution obtained from vortex-lattice theory. Figure 6-1 displays the appropriate input deck. Figure 6-2 shows the mean material trajectories, and Figure 6-3 gives the Gaussian deposition for a release of 1 gallon/minute/nozzle.

2. The second test case examines the wake behind a wide body C-130 transport plane. Figure 6-4 displays the appropriate input deck. Figure 6-5 shows the mean material trajectories for the assumed nozzle release points (the four propellers skew the solution); Figure 6-6 shows the paths of the tip vortices and the four propellers, and Figure 6-7 shows the continuous ground deposition for a release of 1 gallon/minute/nozzle.

3. The third test case examines the wake behind a Cessna 188 AgTruck in forward flight (Mission test run 14, droplet size 171 microns, Ref. 30). Figure 6-8 displays the input deck while Figure 6-9 shows the mean material trajectories and Figure 6-10 gives the Gaussian ground deposition for a release of 0.1 gallon/minute/nozzle. Figure 6-11 illustrates the equivalent Gaussian distribution, Figure 6-12 shows the time history of the evaporating diameter of one droplet in the simulation, Figures 6-13, 6-14 and 6-15 give the droplet velocity time histories, and Figure 6-16 shows the deposition on a spherical collector.

4. The fourth test case examines a Hiller 12E helicopter (Chico test run B-2, Ref. 27). Figure 6-17 displays the input file, while Figure 6-18 shows the mean material trajectories. Figure 6-19 displays contours of canopy deposition, while Figure 6-20 summarizes the total deposition in the canopy, on the same scales as the continuous ground deposition, Figure 6-21. Figure 6-22 illustrates the crosswind velocity profile, Figure 6-23 illustrates the canopy plant area fraction, Figure 6-24 gives the canopy deposition fraction for a droplet in the simulation, and Figure 6-25 summarizes the drift fraction for the simulation (since there is no evaporation, the final drift fraction will reach a value of zero).

```
0000  F-15
0010  50.0  1
0011  100  0  1  0
0020  0  6.67  20.0  170.0
0025    0.0     139.288
0025    0.102   139.288
0025    0.297   139.158
0025    0.482   138.911
0025    0.668   138.540
0025    0.853   138.045
0025    1.038   137.424
0025    1.223   136.678
0025    1.409   135.805
0025    1.594   134.805
0025    1.779   133.677
0025    1.965   132.418
0025    2.150   131.028
0025    2.335   129.505
0025    2.520   127.845
0025    2.706   126.046
0025    2.891   124.104
0025    3.076   122.017
0025    3.262   119.779
0025    3.447   117.385
0025    3.632   114.828
0025    3.817   112.097
0025    4.016   109.087
0025    4.215   105.890
0025    4.400   102.636
0025    4.586    99.170
0025    4.771    95.449
0025    4.956    91.428
0025    5.142    87.053
0025    5.327    82.248
0025    5.512    76.906
0025    5.697    70.873
0025    5.859    64.330
0025    6.022    56.753
0025    6.207    47.080
0025    6.392    35.380
0025    6.577    20.145
0025   -6.670     0.0
0035  95400.0  0.5  -0.6  3.0
0045  2  0.6  -0.6
0050  0  1.0
0060  2  0  -1.0  -0.5  300.0  1.0
```

Figure 6-1.  AGDISP input file for Example Case 1.

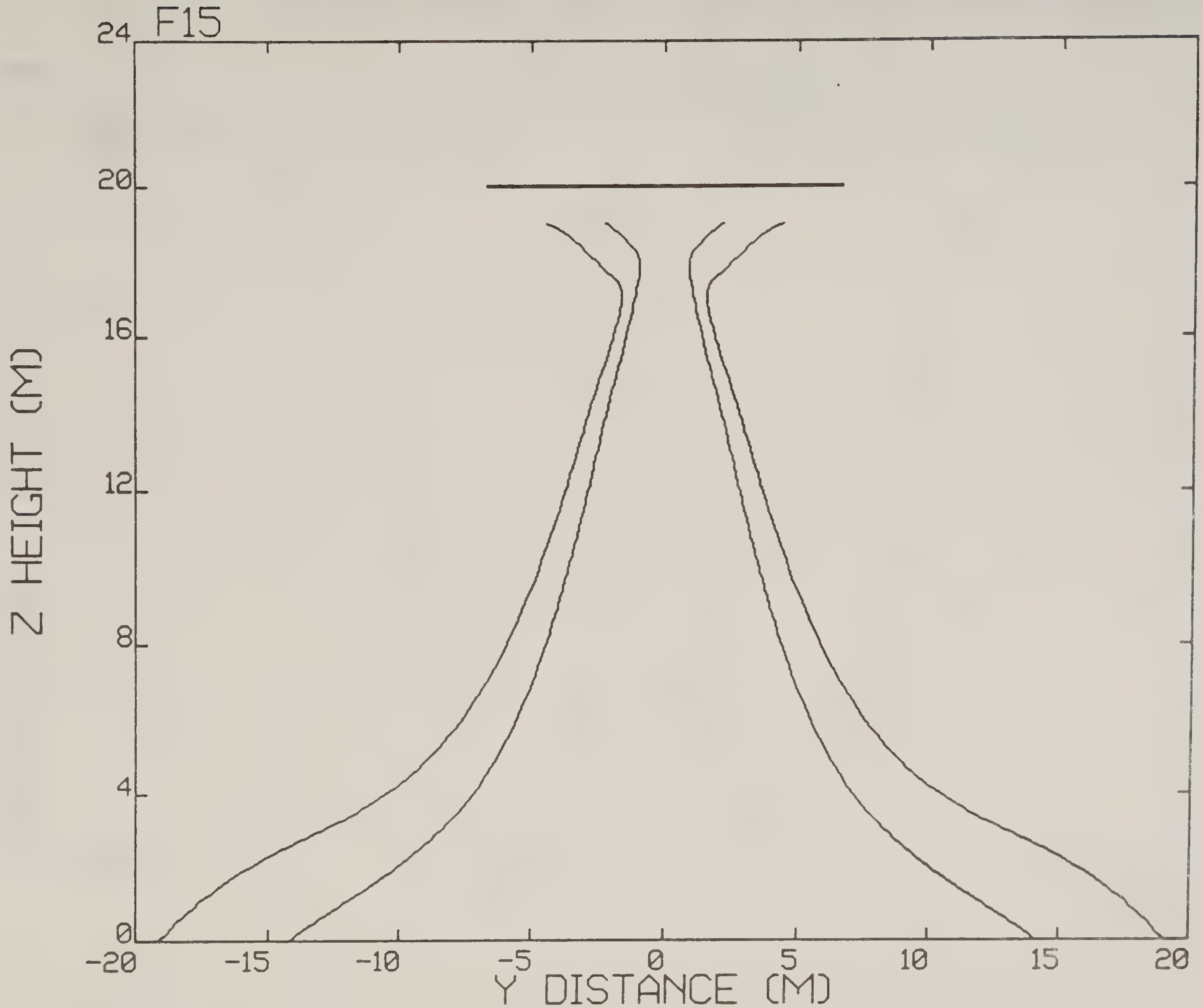



Figure 6-2. Mean material paths for the F-15 Example Case 1. The wing position is given by the double-wide solid line.

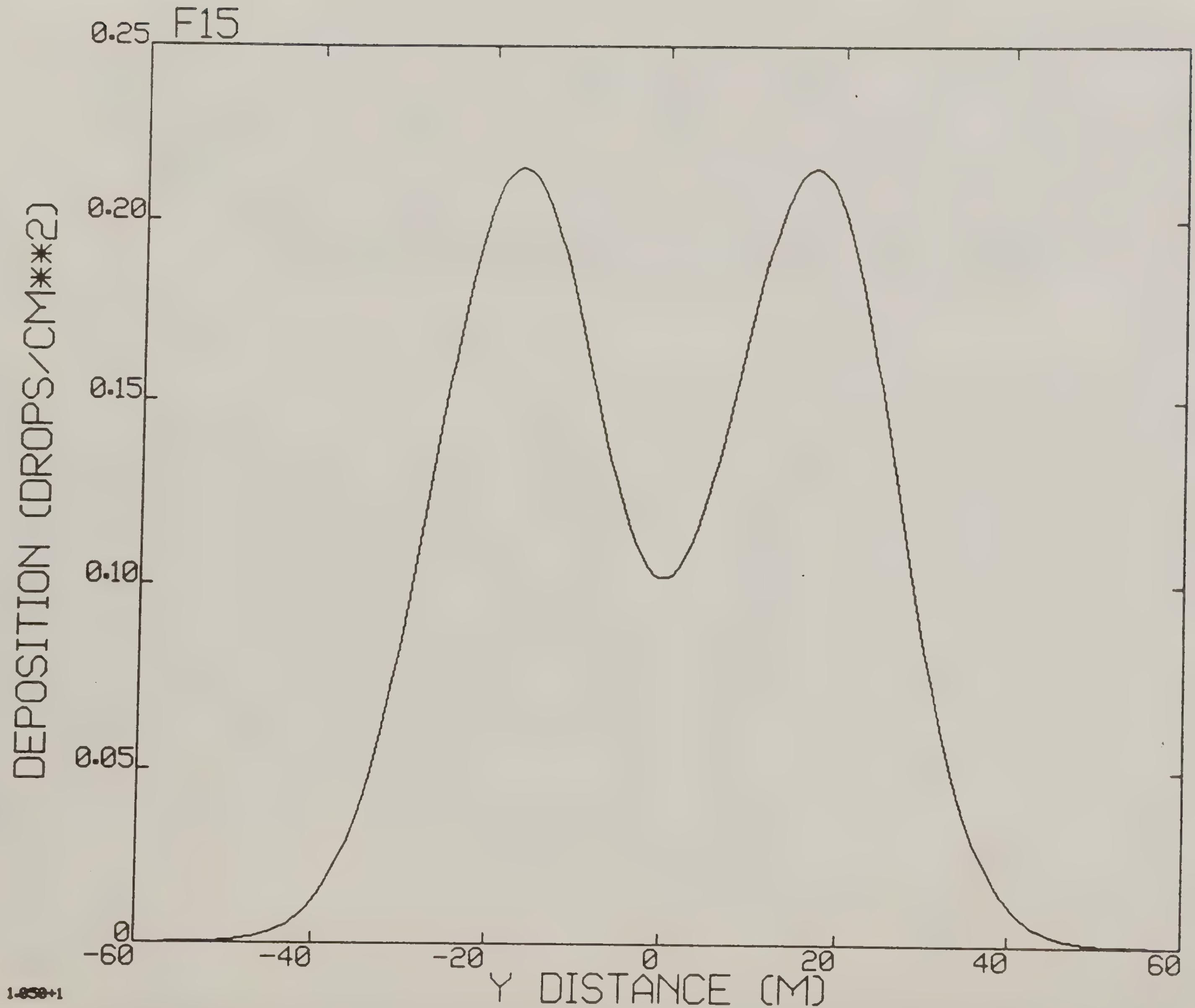



Figure 6-3. Gaussian ground deposition for the F-15 Example Case 1. Here the mass flow rate was assumed at 1 gallon/minute/nozzle. The integrated deposition is shown as 10.50 m-drops/$cm^2$.

```
0000  C-130
0010  30.0  2
0011  100  100  0  0
0020  2  20.2  20.0  150.0
0023  625000.0
0040  0.1  40.0  0.8  2500.0  2.05  -0.9  -5.0
0045  4  5.1  -0.9  10.1  -0.9
0050  0  1.0
0060  -2  0  -3.8  0.0  200.0  1.0
0061 -12.5   -3.8
0061   -5.0  -3.8
0061    5.0  -3.8
0061   12.5  -3.8
0080  -14.0  -2.6
0081    0.0   0.0
0081    4.5   7.21
0081    8.8   7.58
0081   13.3   9.53
0081   16.7   7.91
0081   18.0   6.76
0081   20.0   5.88
0081   22.2   3.06
0081   24.0   2.05
0081  -29.2   0.0
```

Figure 6-4. AGDISP input file for Example Case 2.

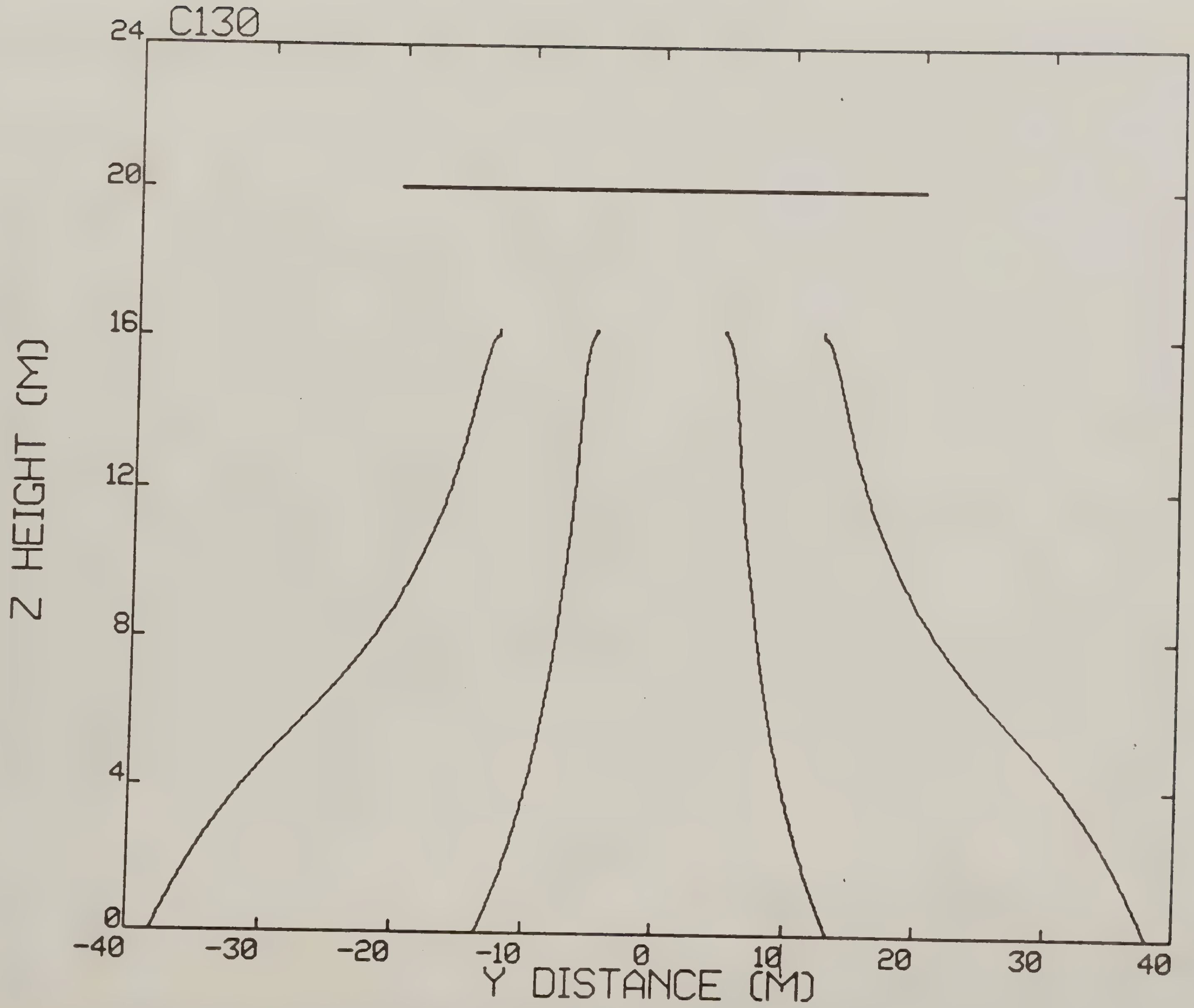



Figure 6-5. Mean material paths for the C-130 Example Case 2.

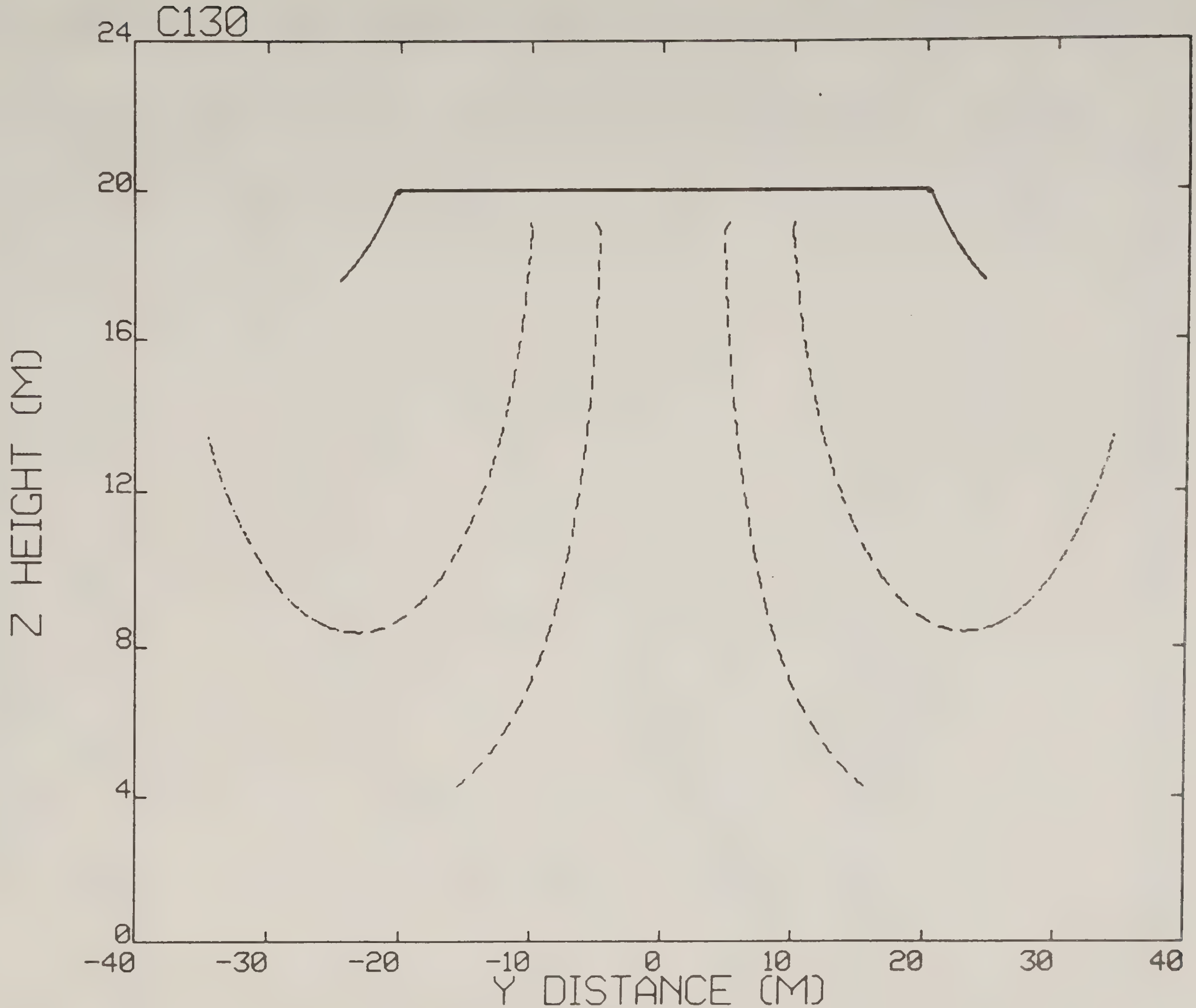



Figure 6-6. Paths of the tip vortices (solid lines) and engine centerlines (dashed lines) for the C-130 Example Case 2. The double-wide solid line is the wing location.

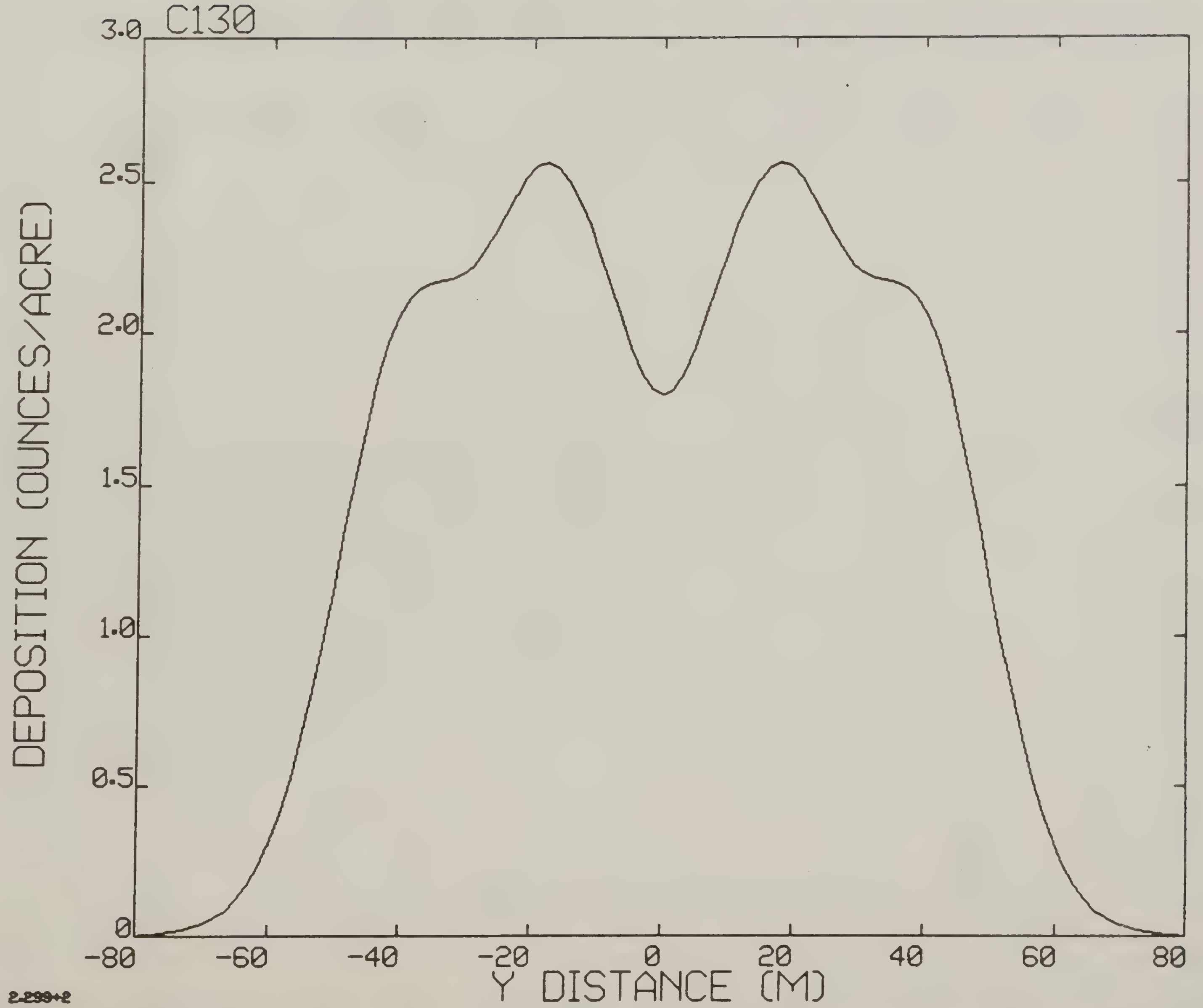



Figure 6-7. Continuous ground deposition for the C-130 Example Case 2. Here the mass flow rate was assumed at 1 gallon/minute/nozzle. The integrated deposition is shown as 229.9 m-ounces/acre.

```
0000  CESSNA 188 AGTRUCK -- 171.0 MICRON DIAMETER -- RUN 14
0010  180.0  2
0011  100  0  0  0
0020  2  6.37  15.55  49.6
0023   14362.5
0028  6.11  10.0  0.0134  1.25
0040  0.1  19.05  0.8  2400.0  1.02  -0.4  0.0
0050  0  0.0
0060  -23  -1  0.0  0.0  171.0  1.0
0061   -5.093   -0.244
0061   -4.940   -0.257
0061   -4.788   -0.295
0061   -4.623   -0.339
0061   -4.470   -0.396
0061   -4.318   -0.422
0061   -4.166   -0.447
0061   -4.007   -0.485
0061   -3.848   -0.523
0061   -3.696   -0.549
0061   -3.543   -0.600
0061   -3.378   -0.625
0061   -3.188   -0.650
0061   -3.035   -0.676
0061   -2.883   -0.695
0061   -2.724   -0.708
0061   -2.572   -0.739
0061   -2.413   -0.752
0061   -2.261   -0.777
0061   -2.108   -0.790
0061   -1.956   -0.822
0061   -1.638   -0.847
0061   -1.334   -0.892
0061    1.334  -0.892
0061    1.499  -0.873
0061    1.651  -0.854
0061    1.803  -0.828
0061    1.962  -0.815
0061    2.273  -0.777
0061    2.426  -0.752
0061    2.584  -0.746
0061    2.743  -0.714
0061    2.896  -0.695
0061    3.048  -0.676
0061    3.200  -0.650
0061    3.397  -0.625
0061    3.556  -0.600
0061    3.708  -0.568
0061    3.861  -0.542
0061    4.013  -0.511
0061    4.166  -0.485
0061    4.318  -0.447
0061    4.477  -0.434
0061    4.636  -0.396
0061    4.788  -0.365
0061    4.934  -0.333
0061    5.105  -0.295
0065  3.65  132.4
```

Figure 6-8. AGDISP input file for Example Case 3.

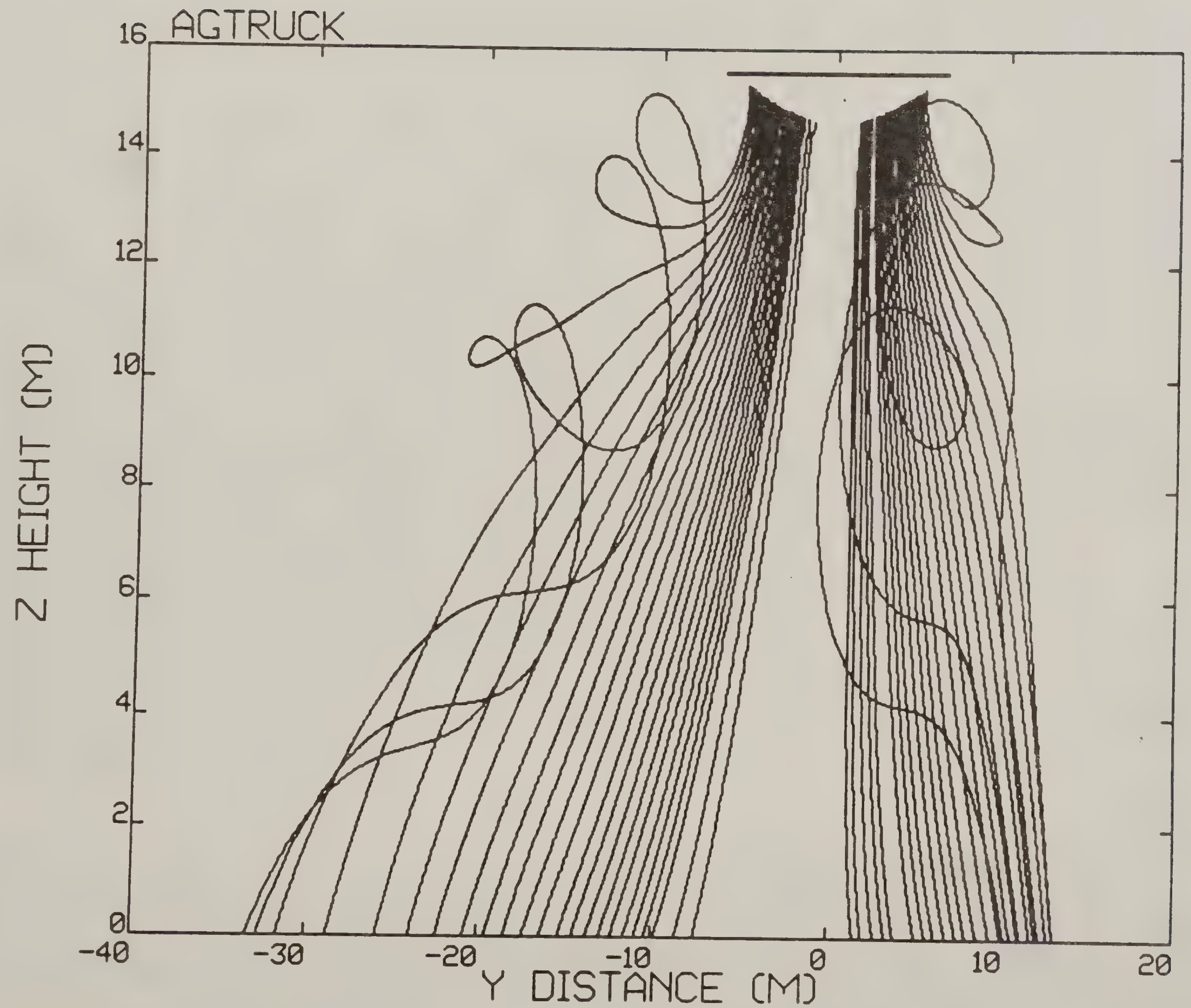



Figure 6-9. Mean material paths for the Cessna 188 AgTruck Example Case 3.

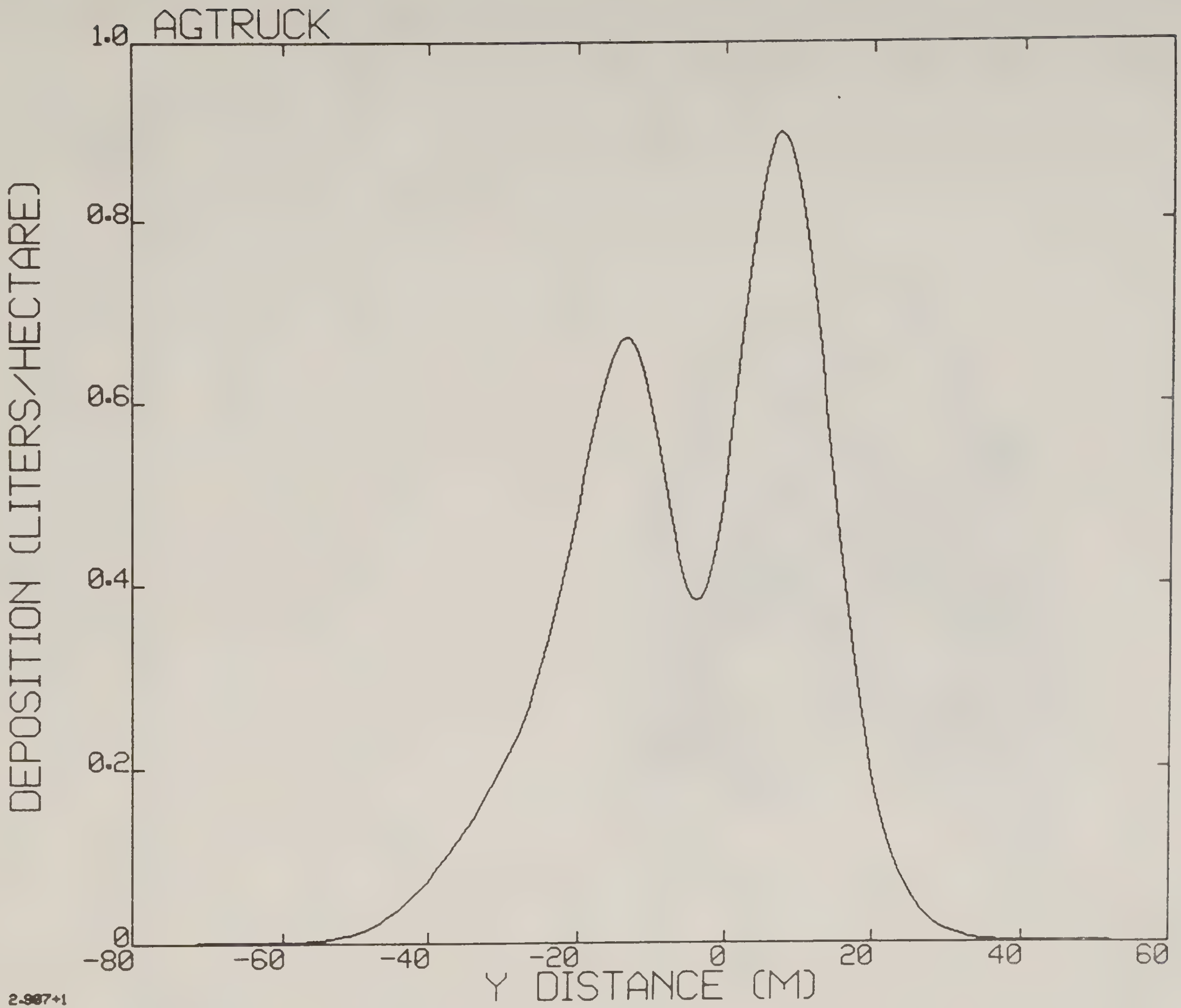



Figure 6-10. Gaussian ground deposition for the Cessna 188 AgTruck Example Case 3. Here the mass flow rate was assumed at 0.1 gallon/minute/nozzle. The integrated deposition is shown as 29.07 m-liters/hectare.

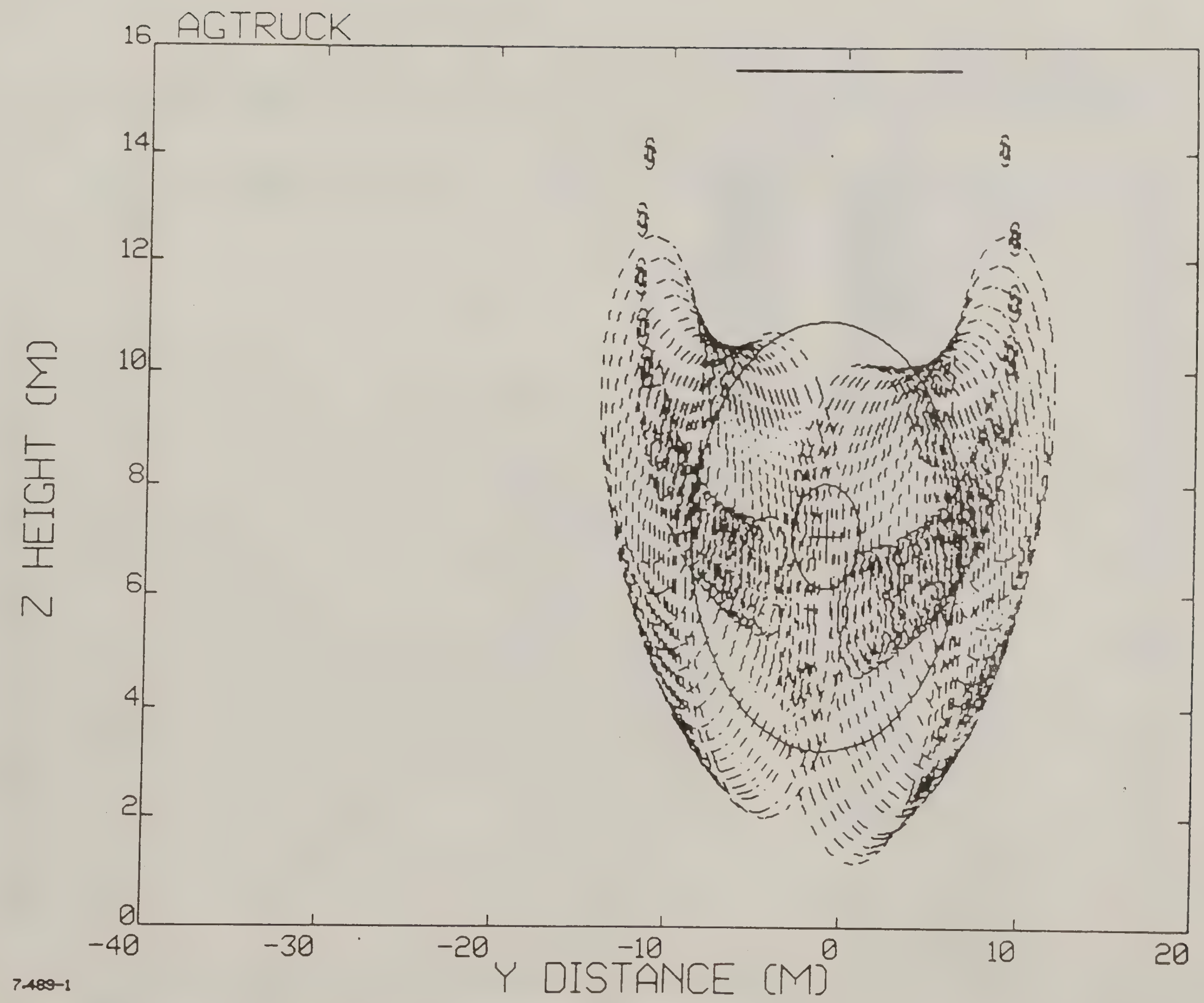



Figure 6-11. Equivalent Gaussian distribution for the Cessna 188 AgTruck Example Case 3. Here two circles (dashed lines) define the location of each material droplet in the simulation, and two circles (solid lines) define the equivalent Gaussian location, with a Figure of Merit shown as 0.7489 at a time of 8.358 seconds.

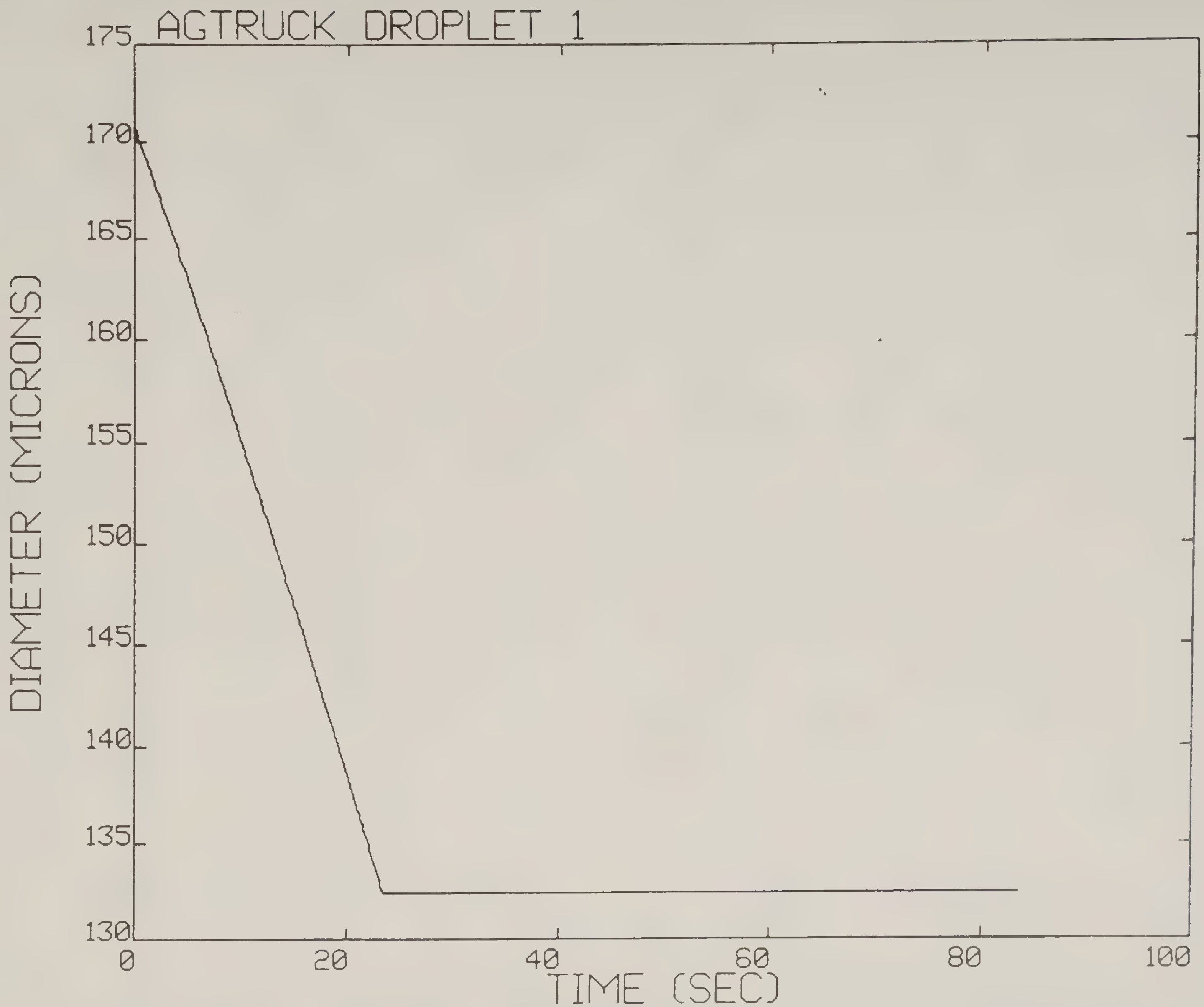



Figure 6-12. Diameter time history for the first droplet in the Cessna 188 AgTruck Example Case 3. The droplet begins with a size of 171 microns and evaporates down to a size of 132.4 microns, then remains in the simulation until hitting the surface.

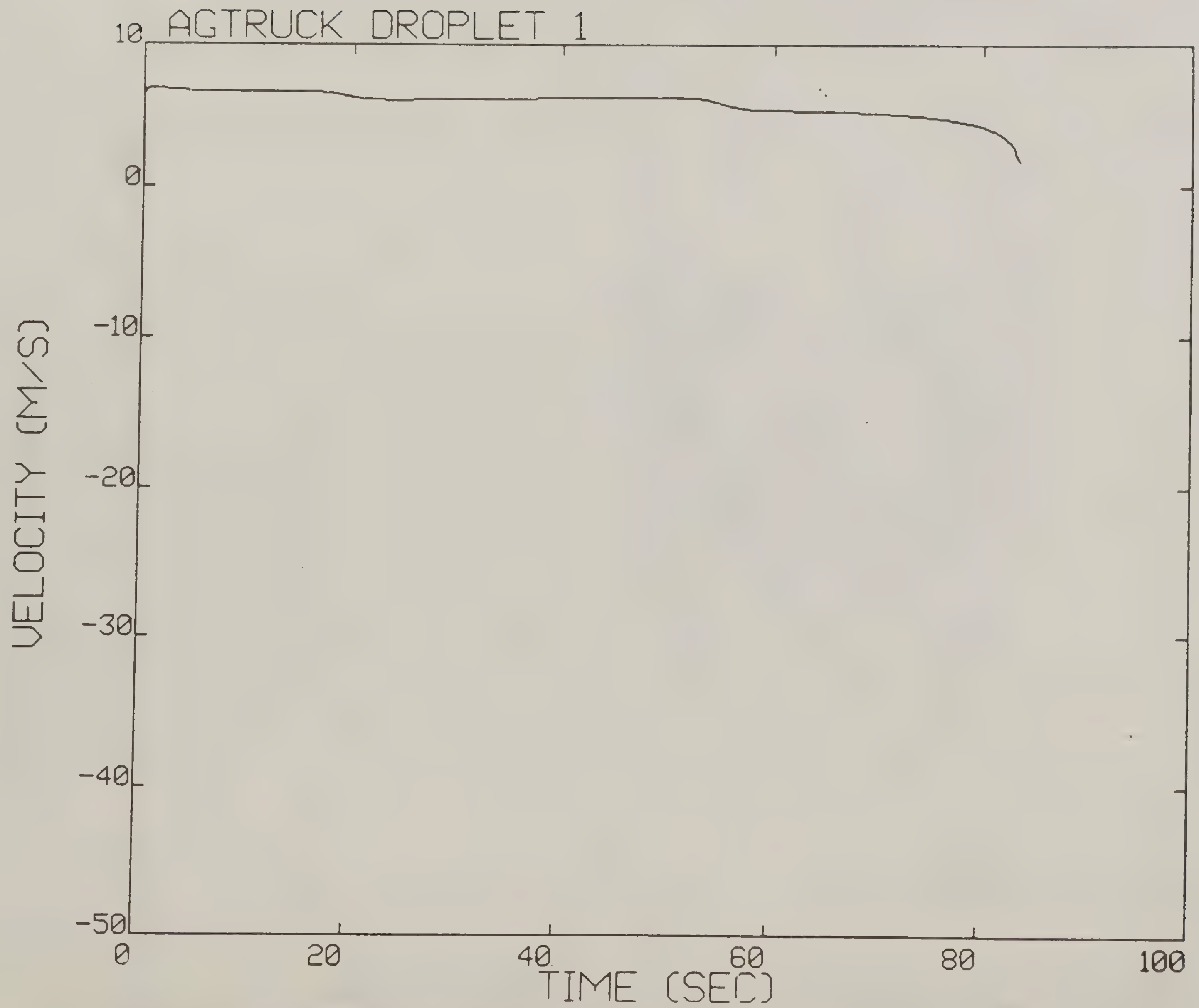



Figure 6-13. Axial (U) velocity time history for the first droplet in the Cessna 188 AgTruck Example Case 3. The droplet is released at the speed of the aircraft (-49.6 m/sec) and quickly adjusts to an ambient velocity of approximately 5 m/sec.

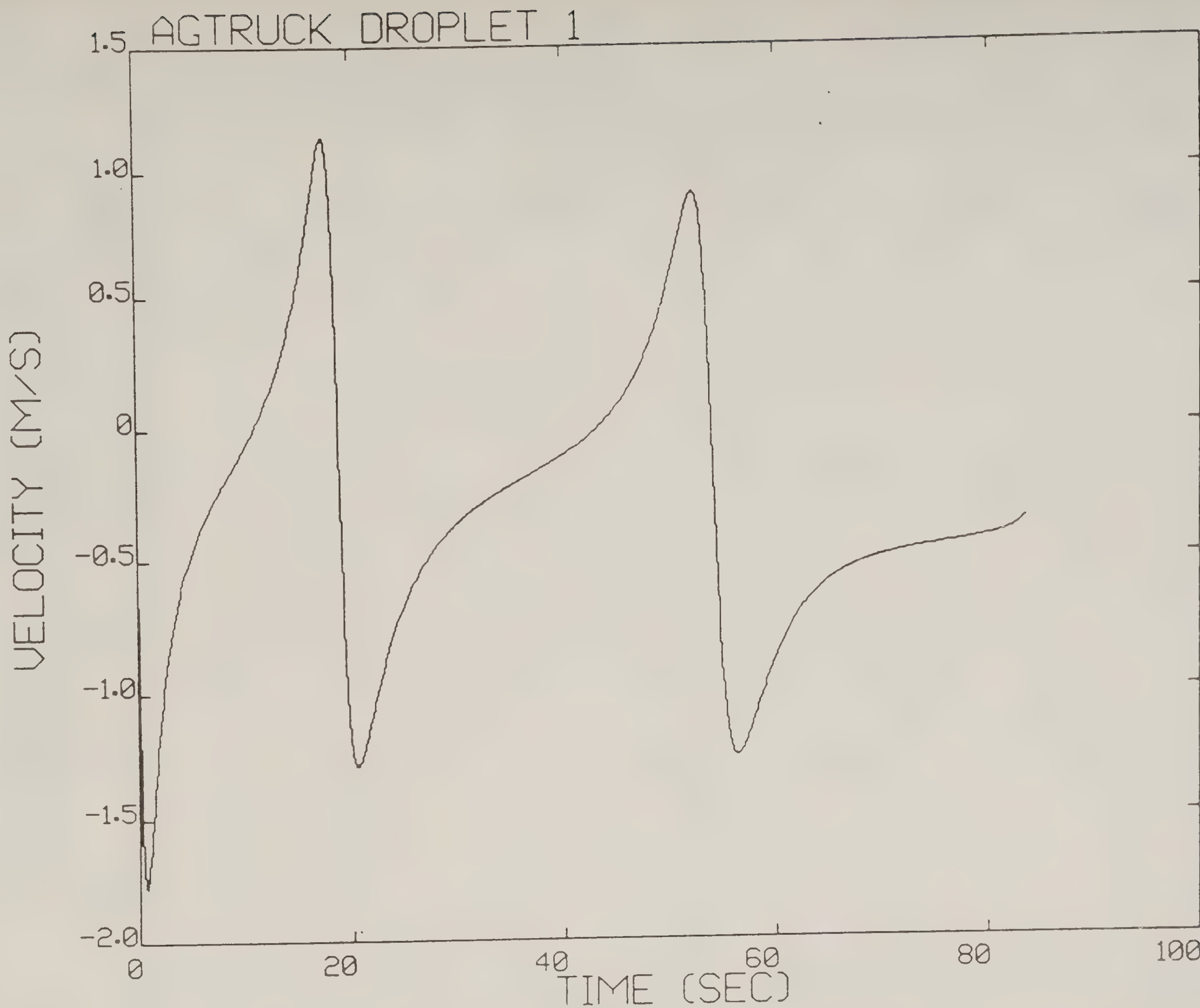



Figure 6-14. Horizontal (V) velocity time history for the first droplet in the Cessna 188 AgTruck Example Case 3. The droplet horizontal velocity is repeatedly corrected for the effect of the encountering wing tip vortices (see Figure 6-9 for the trajectory of the droplet).

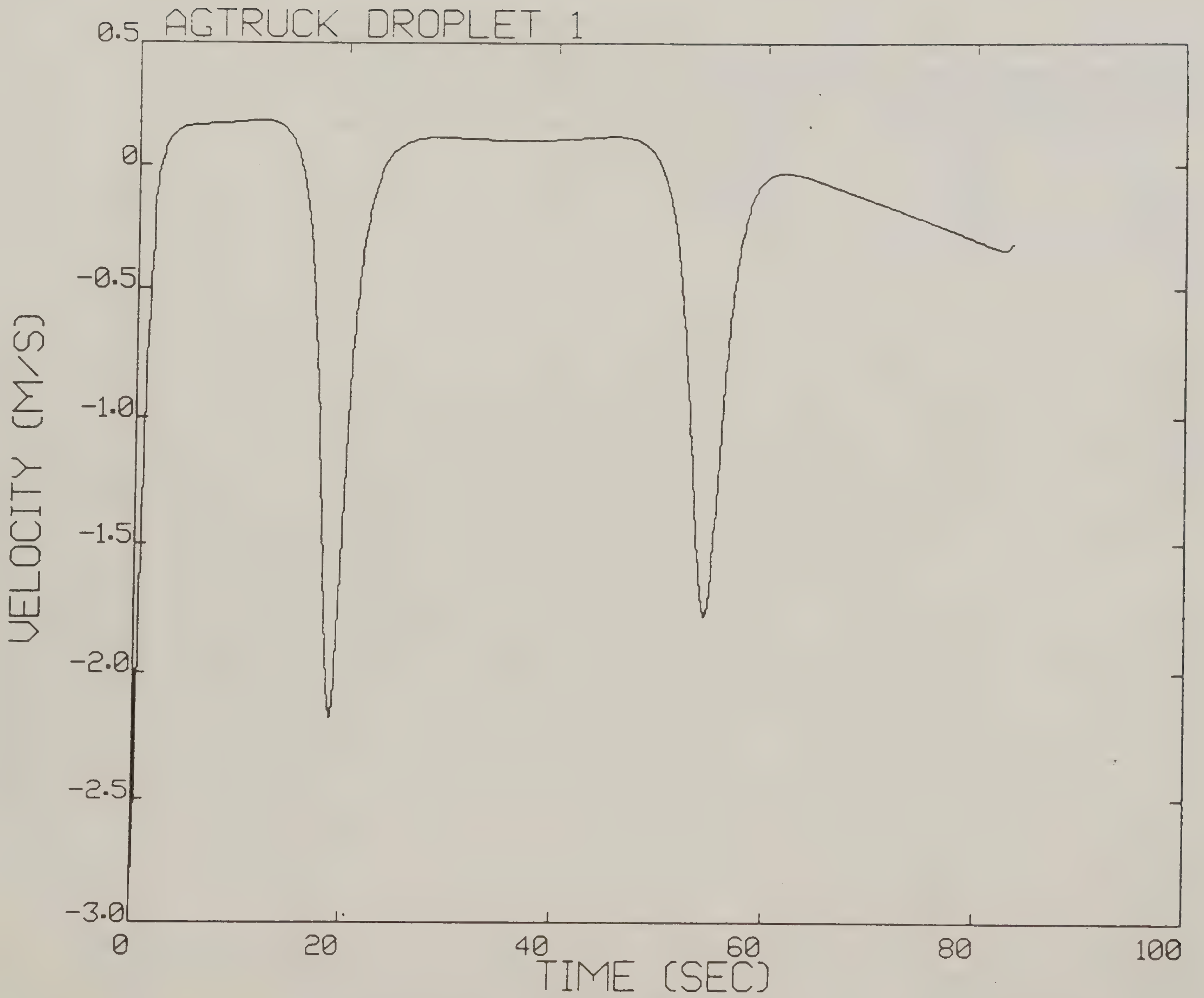
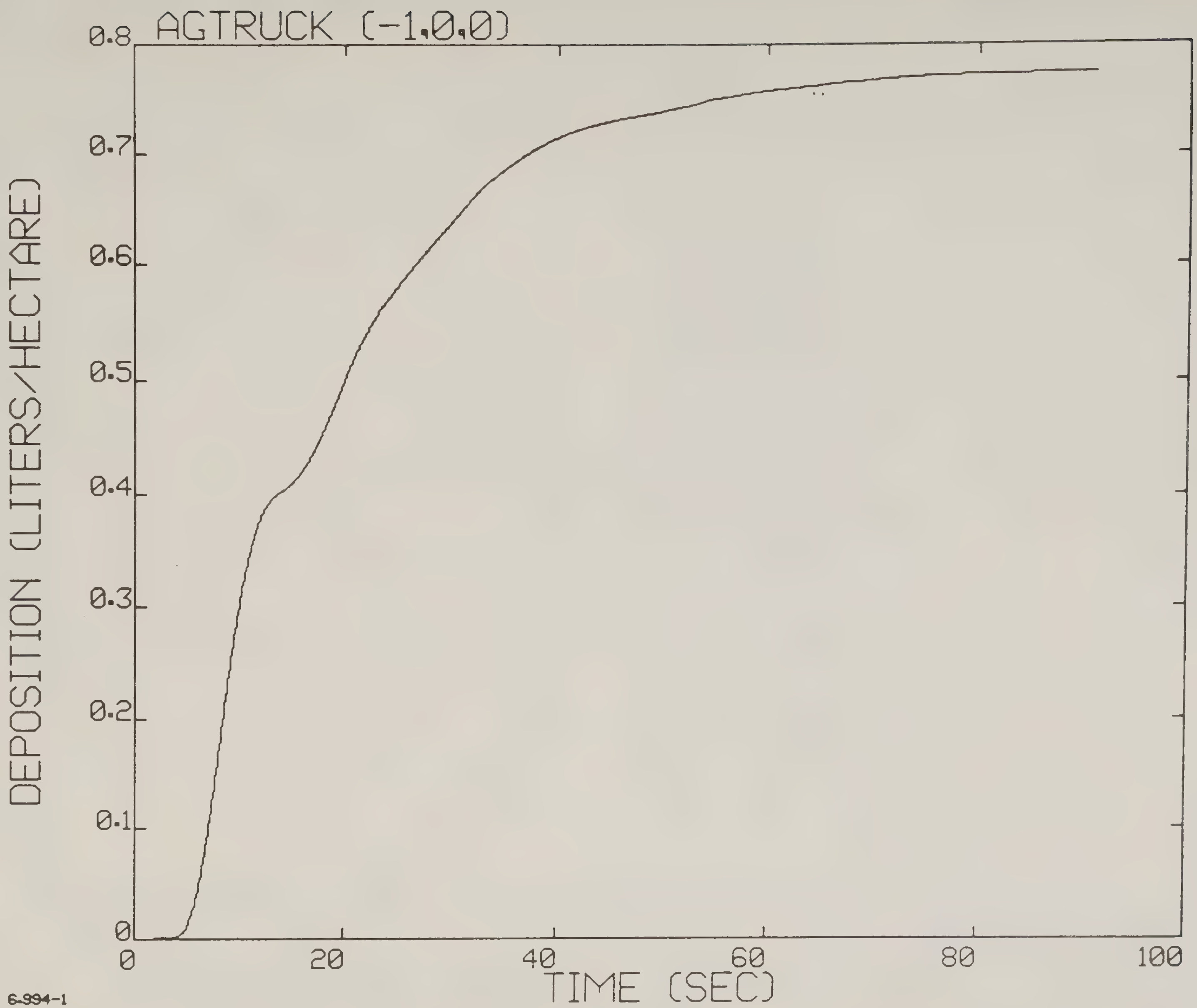



Figure 6-15. Vertical (W) velocity time history for the first droplet in the Cessna 188 AgTruck Example Case 3. The droplet vertical velocity is repeatedly corrected for the effect of the encountering wing tip vortices (see Figure 6-9 for the trajectory of the droplet).




6-994-1

Figure 6-16. Deposition on the upstream side of a 0.075-meter-diameter sphere placed in the Cessna 188 AgTruck Example Case 3 flowfield at a position of $y = -10m$, $z = 2m$. The target collection efficiency is shown as 0.6994.

```
0000 CHICO B-2: HILLER 12E
0010  150.0  2
0011  100  0  0  0
0020  4  5.4  14.20  11.09
0028  1.2  16.0  0.1  67.0
0030  10325.0  400.0
0050  0  0.0
0055   0.0  0.044
0055   0.6  0.044
0055   1.8  0.147
0055   3.1  0.221
0055   4.3  0.191
0055   5.5  0.150
0055   6.7  0.074
0055  -7.3  0.0
0056  0.2
0060  -14  0  0.0  0.0  251.0  1.0
0061  -4.12  -2.0
0061  -3.81  -2.0
0061  -3.51  -2.0
0061  -3.20  -2.0
0061  -2.90  -2.0
0061  -2.59  -2.0
0061  -2.29  -2.0
0061  -1.98  -2.0
0061  -1.68  -2.0
0061  -1.37  -2.0
0061  -1.07  -2.0
0061  -0.76  -2.0
0061  -0.46  -2.0
0061  -0.15  -2.0
0061   0.15  -2.0
0061   0.46  -2.0
0061   0.76  -2.0
0061   1.07  -2.0
0061   1.37  -2.0
0061   1.68  -2.0
0061   1.98  -2.0
0061   2.29  -2.0
0061   2.59  -2.0
0061   2.90  -2.0
0061   3.20  -2.0
0061   3.51  -2.0
0061   3.81  -2.0
0061   4.12  -2.0
```

Figure 6-17. AGDISP input file for Example Case 4.

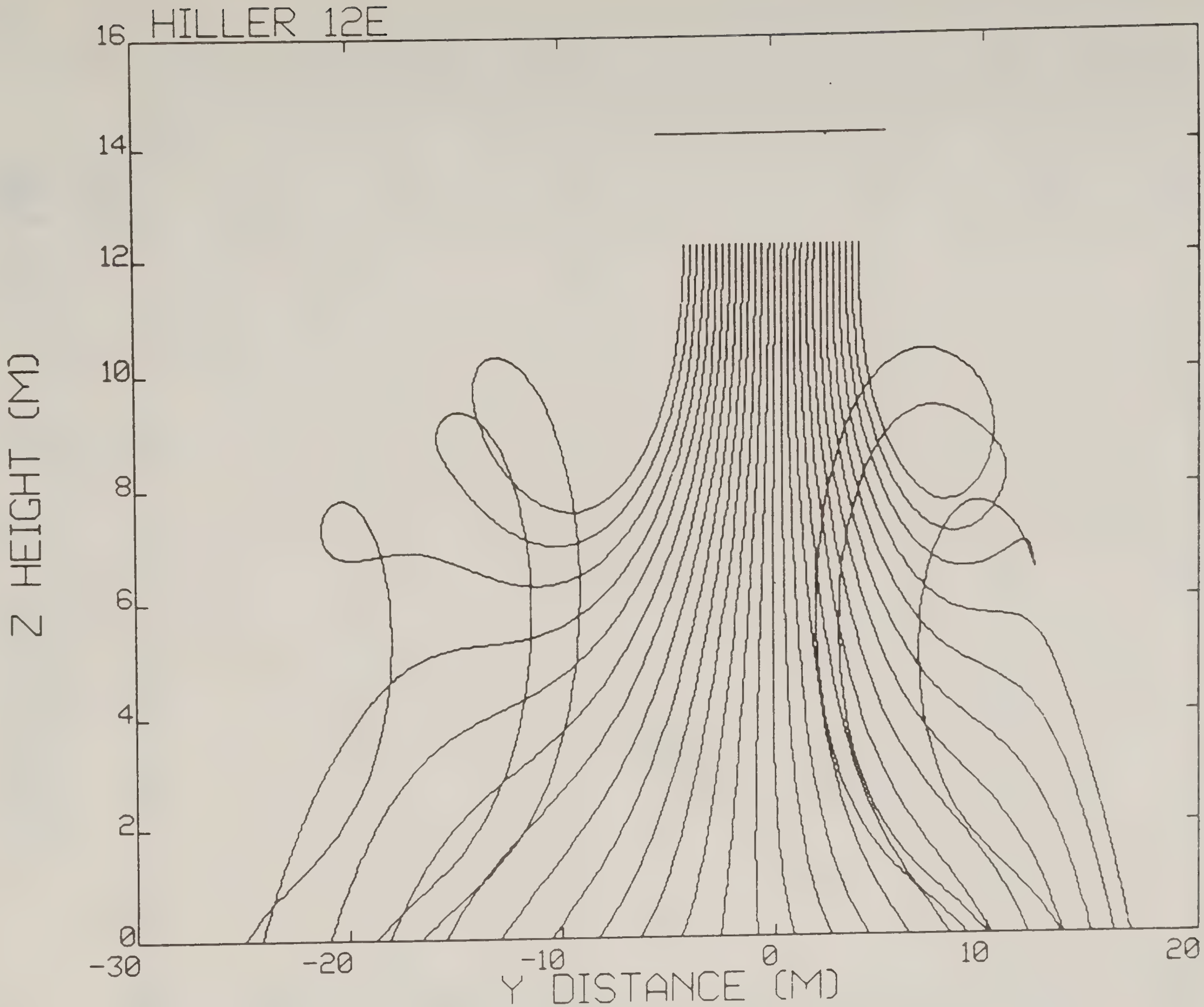



Figure 6-18. Mean material paths for the Hiller 12E Example Case 4.

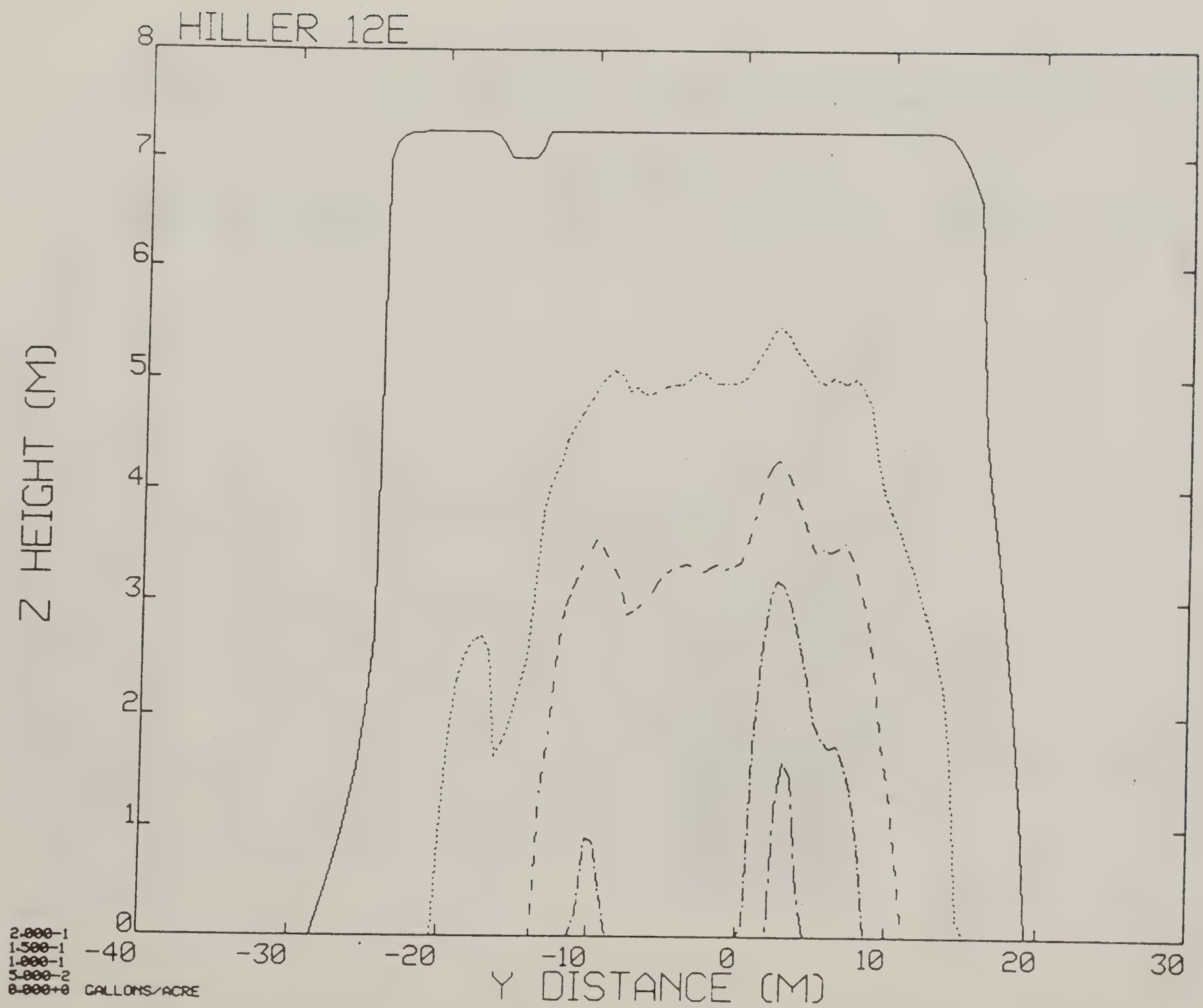



Figure 6-19. Canopy deposition contours for the Hiller 12E Example Case 4. Here the mass flow rate was assumed at 0.1 gallon/minute/nozzle. The outermost contour (solid line) is near 0, and the interior contours increase levels by 0.05 gallon/acre as shown. The maximum contour value is 0.2 gallon/acre.

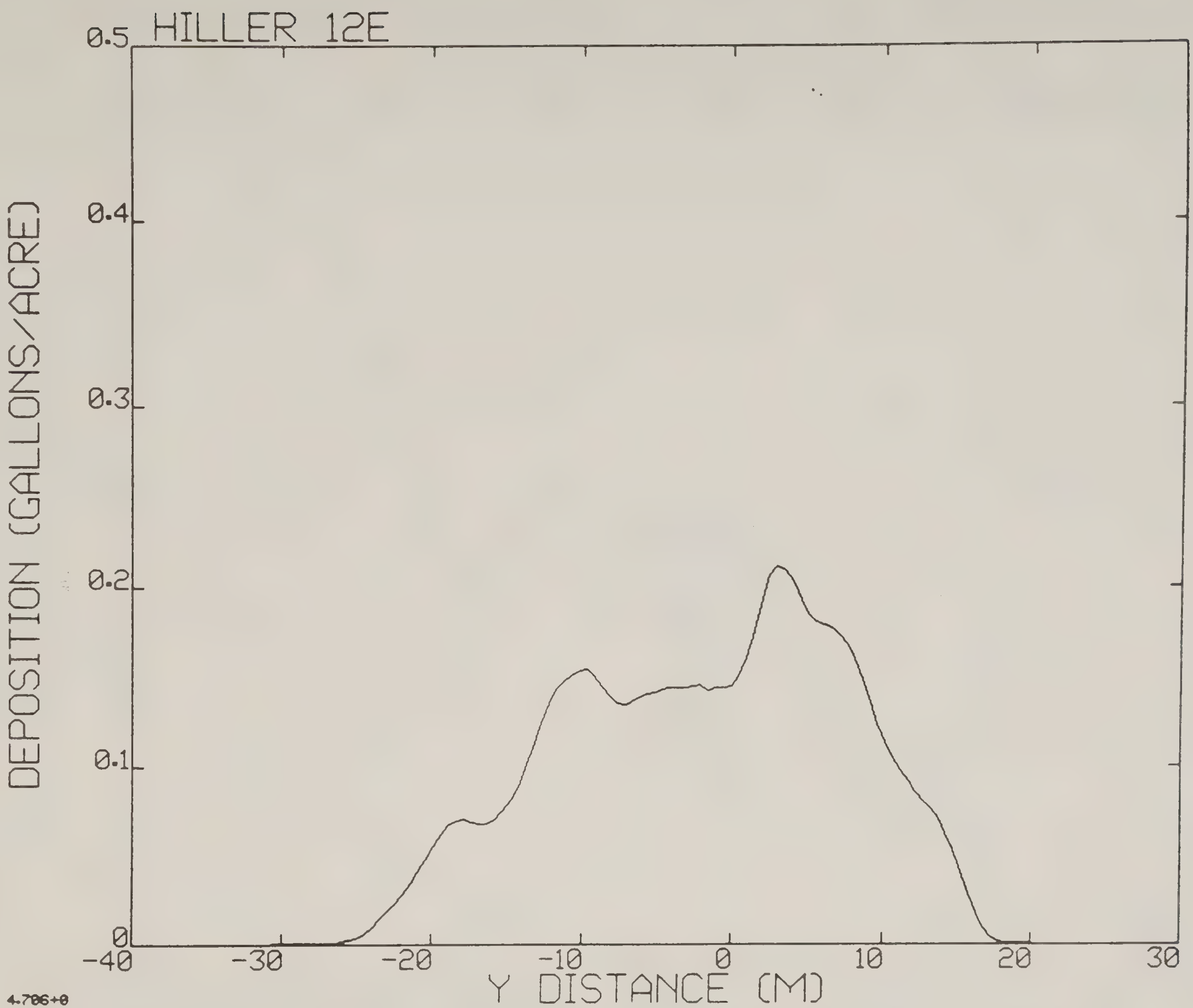



Figure 6-20. Total canopy deposition for the Hiller 12E Example Case 4. The integrated deposition is shown as 4.706 m-gallons/acre.


Figure 6-21. Continuous ground deposition for the Hiller 12E Example Case 4. The integrated deposition is shown as 12.32 m-gallons/acre.

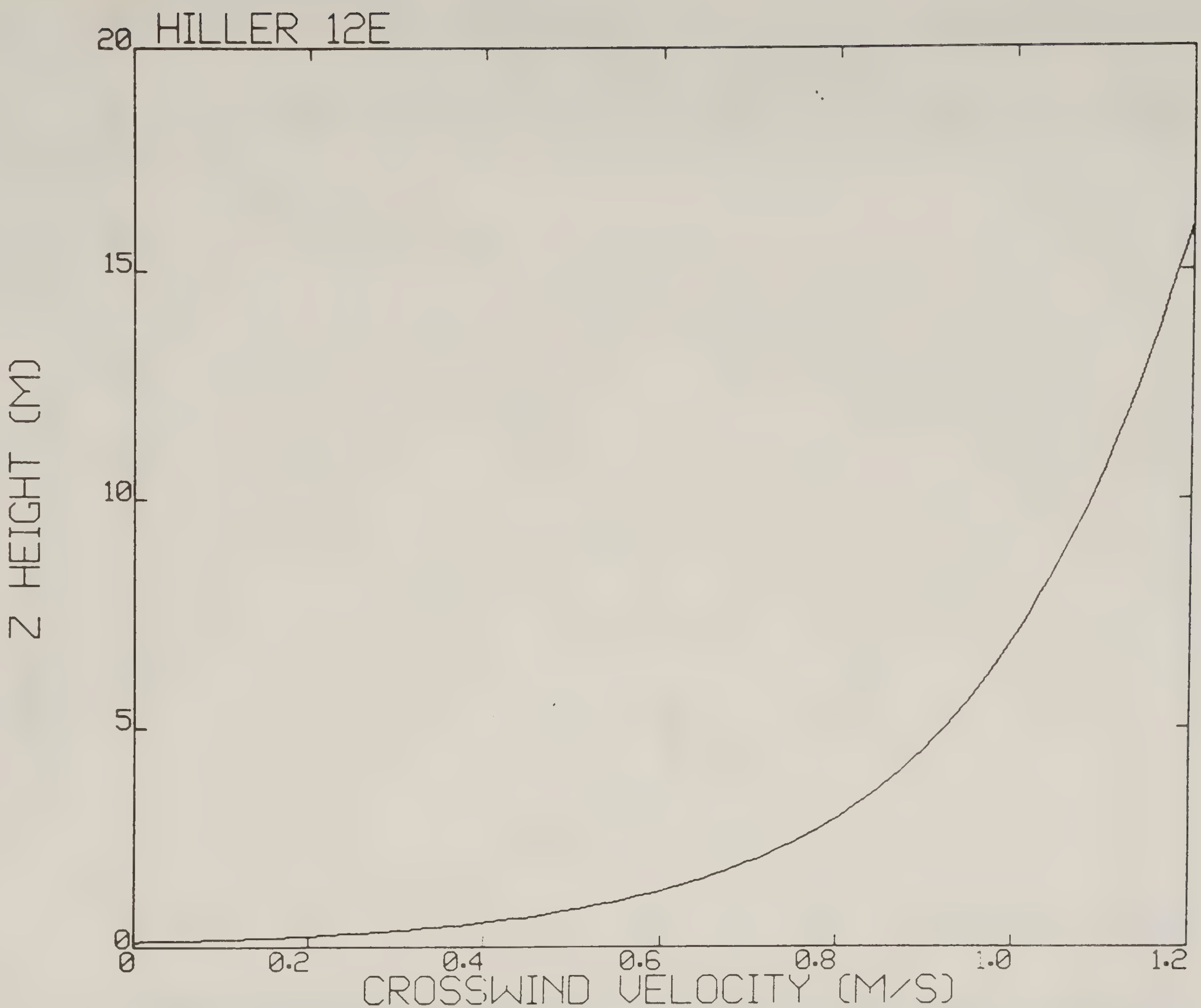



Figure 6-22. Crosswind velocity profile for the Hiller 12E Example Case 4.

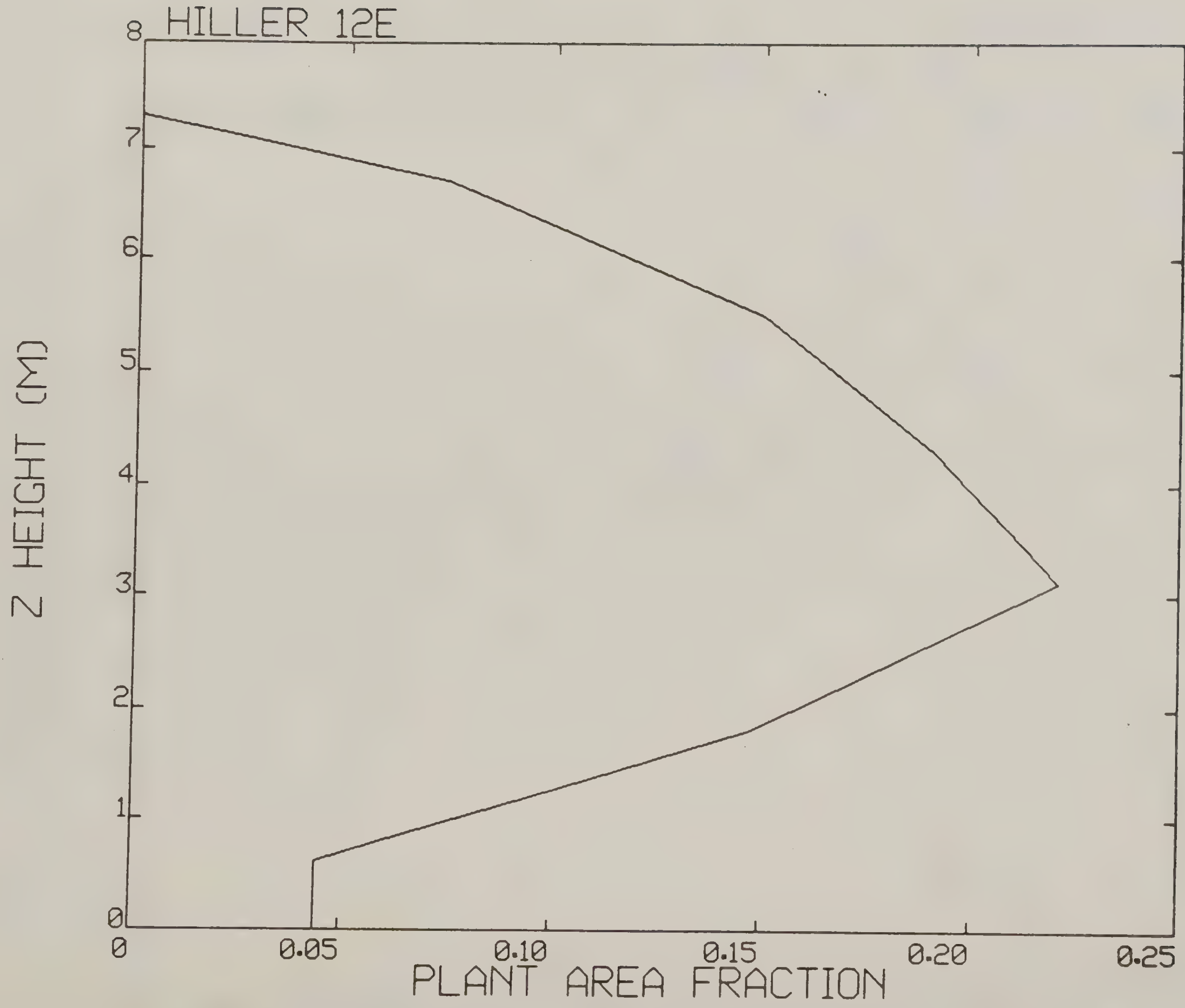



Figure 6-23. Plant area fraction profile for the Hiller 12E Example Case 4.

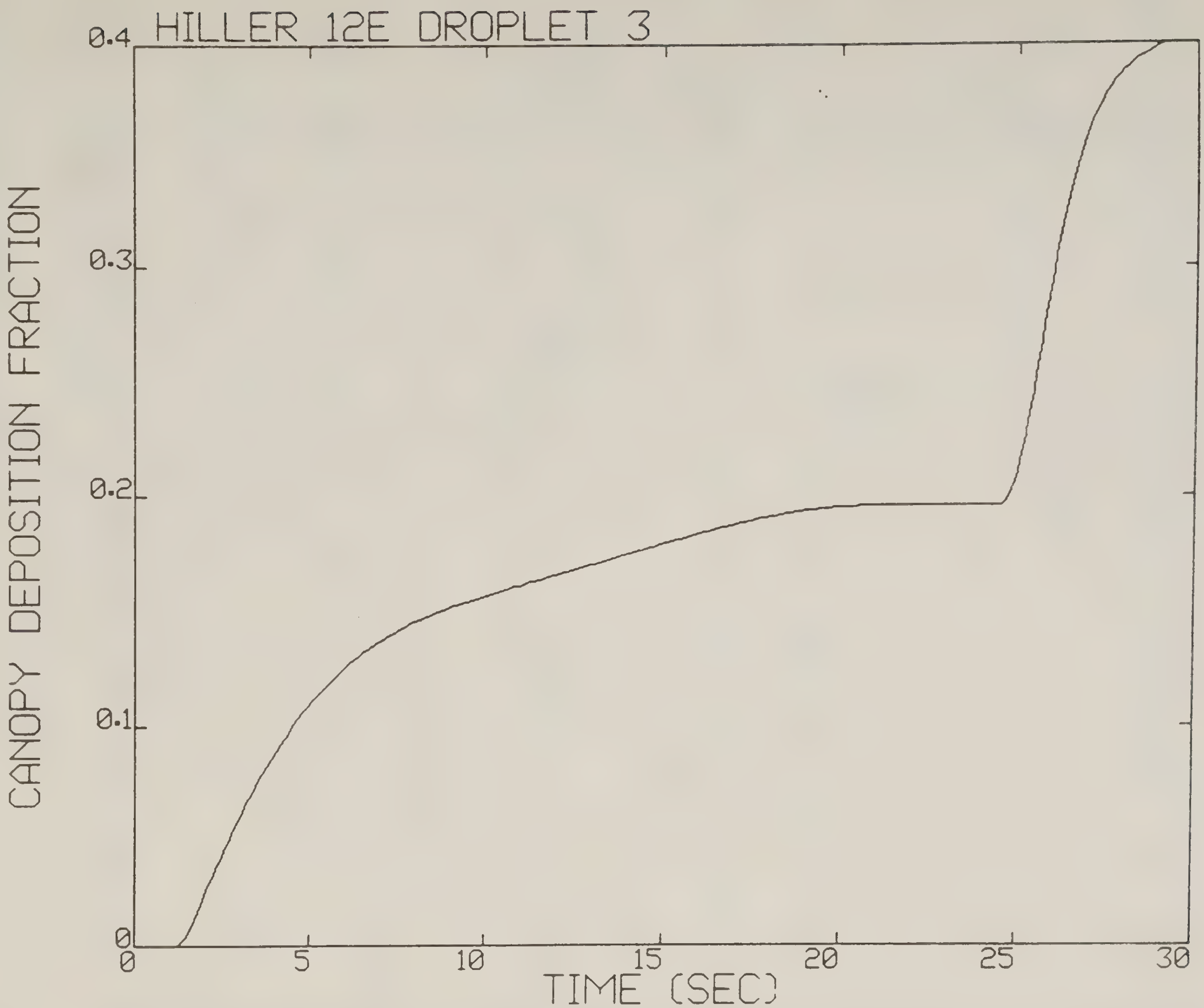



Figure 6-24. Canopy deposition fraction for the third droplet in the Hiller 12E Example Case 4. The trajectory of the droplet is shown in Figure 6-18. It may be seen that at surface impact the droplet has deposited 40 percent of its initial material in the canopy.

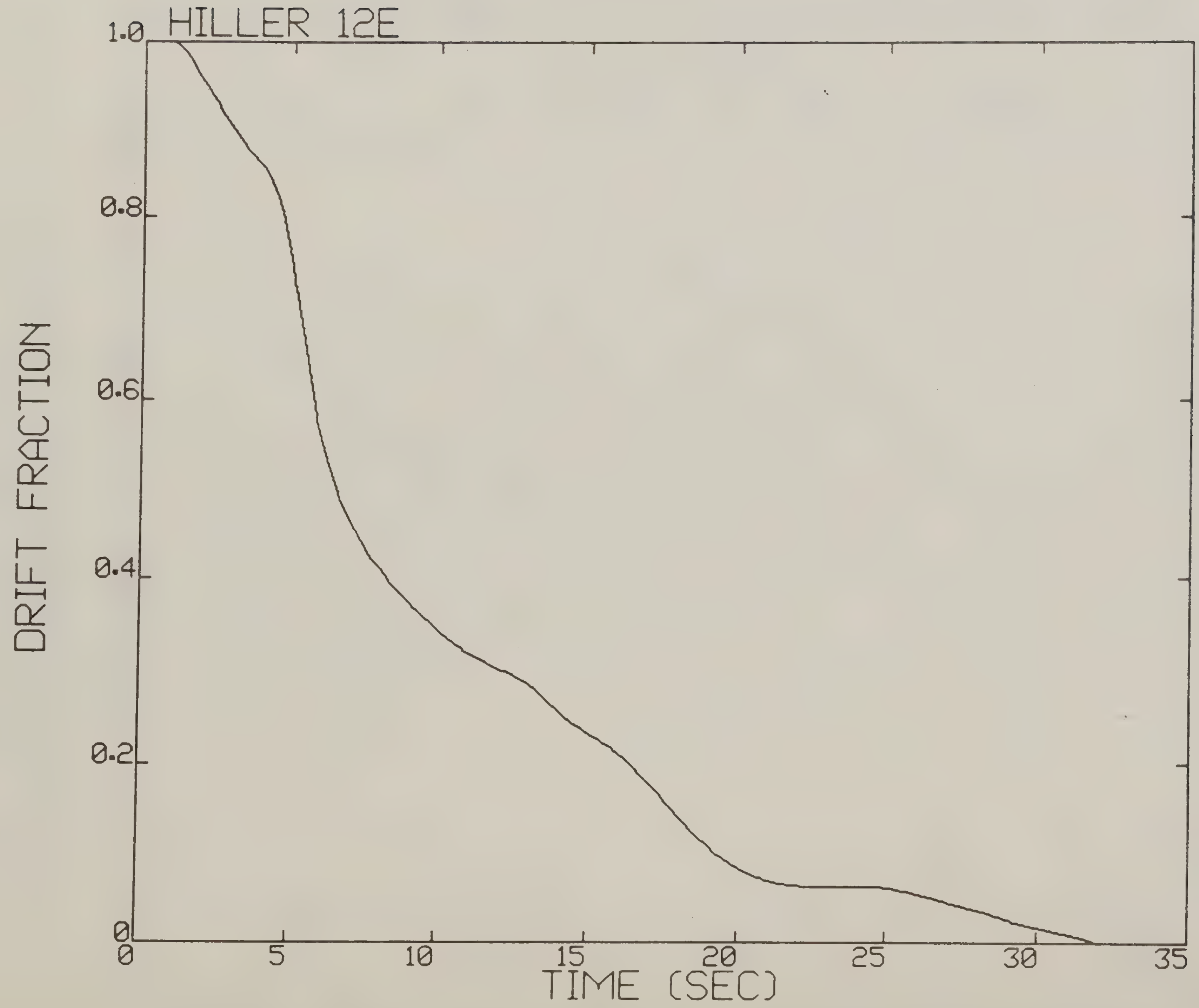



Figure 6-25. Drift fraction time history for the Hiller 12E Example Case 4.

# 7. USING AGDISP AND AGPLOT

AGDISP and AGPLOT are operational on several computer systems. For completeness, the Univac 1108 system at Ft. Collins will also be discussed, although AGDISP Mod 4.0 is its highest level of operation.

## Operation on the Data General MV-15000

AGDISP and AGPLOT are run on the Data General Forest Service network by the commands

```
XEQ  AGDISP

XEQ  AGPLOT
```

with resolution of the file names and extensions performed within the programs.

The plotting package GKS is invoked to plot AGPLOT results onto graphics output devices.

## Operation on an IBM PC/XT/AT

AGDISP on a PC is detailed in Ref. 32, with only a summary given here. The DOS operating system does not contain ASSIGN commands; therefore, all necessary files must be transferred to AGDISP and AGPLOT on the command line. A typical AGDISP input would be

```
AGDISP  FILENAME.INP  CASEFILE.INP  FILENAME.BIN  PRN
```

where printer output would go directly to the printer. One-line command files (BAT files) may replace the above line with

```
AGD  FILENAME  PRN
```

AGPLOT may be invoked typically with

```
AGPLOT  FILENAME.BIN  FILENAME.PLT
```

to create Tektronix 4025 plotting calls that may be transferred to dot-matrix printers using the proprietary utility AGPRINT.

## Operation on the Dugway Computer

The VAX 11/785 at Dugway is an interactive system, with code operation occurring sufficiently fast that batch usage is unnecessary. However, several procedures need to be reviewed to make the operation of AGDISP and AGPLOT more efficient.

Table 7-1 summarizes the command files needed to run AGDISP and AGPLOT. In AGDISP the ASSIGN statement is used to equate the default file names with their appropriate unit numbers.

The AGPLOT command file forces the mount of a scratch magnetic tape, upon which the CALCOMP plotting commands are written. At the conclusion of the AGPLOT run, the computer operator will move the magnetic tape from the VAX 11/785 to the CALCOMP plotter for the actual plotting. Again, the ASSIGN statement equates the default plot file name with the appropriate input unit. If multiple plot files are to be selected, the necessary ASSIGN statements for units 11, 12, 13, etc. must be invoked before running AGPLOT.

In CALCOMP plotting, scale divisions are set at one inch increments. While this restriction produces acceptable plots for preliminary work using the autoscale feature of AGPLOT, it is recommended that any final plots use the manual scale selection procedure. Additionally, there is no feature in CALCOMP to permit plotting only a portion of the data; therefore, all of the data for an AGPLOT option will appear on the CALCOMP plot.

## Operation on the Continuum Dynamics, Inc. Computer

The MicroVAX II at Continuum Dynamics, Inc. operates identically to the VAX at Dugway except for plotting. In general, it may be seen that AGDISP and AGPLOT may both be invoked by command files of the form shown on Table 7-2. In this way input on a file named FILENAME.INP would produce a binary plot file FILENAME.BIN and a printer listing file FILENAME.LIS. Additional files for plotting unit numbers 11, 12, 13, etc., would have to be ASSIGNED before invoking AGPLOT.

Plotting is accomplished by calls to a Tektronix 4025, either directly, or into a .PLT file for later viewing.

## Operation on the Ft. Collins Computer

Normal operation on the Ft. Collins computer system requires the establishment of an input file on unit 4 (with an @USE_4.,INPUTFILE., where the underline denotes a space), a plot file on unit 8 (with a @USE_8.,PLOTFILE.) and a printer file on unit 9 (with an @USE_9.,PRINTFILE.). Terminal output is written to unit 6. This setup is accomplished for an @RUN with the invoking of @ADD_AGDISP.INITIAL. (these features are detailed in Ref. 33). Up to sixteen curves may be plotted on the same multiple deposition plot. For illustration purposes only, we will examine the procedure involved to compute and plot three files, with the generalization obvious. Table 7-3 shows the processing blocks involved. It is assumed that the temporary plot files, PLOT1 and PLOT2, have not been previously assigned; otherwise a simple @ASG,A would be used for each file.

Since the input data is read from INPUTFILE, the editor is used to set up the first set of data. Block 1 is then invoked. The editor is entered to modify INPUTFILE for the second set of data, and Block 2 is invoked. The

TABLE 7-1

Command Procedures for AGDISP and AGPLOT at Dugway

To Invoke AGDISP

```
@AGDISP FILENAME
```

will generate

```
$ASSIGN FILENAME.INP FOR004
$ASSIGN CASEFILE.INP FOR007
$ASSIGN FILENAME.BIN FOR008
$ASSIGN FILENAME.LIS FOR009
$RUN AGDISP
```

To Invoke AGPLOT

```
@AGPLOT FILENAME
```

will generate

```
$ALLOCATE MU CALTAPE:
$MOUNT/NOLABEL/COM = 'CALCOMP' 'AGPLOT' CALTAPE:
$ASSIGN/USER SYS$COMMAND SYS$INPUT
$ASSIGN FILENAME.BIN FOR008
$RUN AGPLOT
$DISMOUNT CALTAPE:
$DEALLOCATE CALTAPE:
$DEASSIGN CALTAPE:
```

TABLE 7-2

Command Procedures for AGDISP and AGPLOT at Continuum Dynamics, Inc.

To Invoke AGDISP

```
@AGDISP FILENAME
```

will generate

```
$ASSIGN/NOLOG  FILENAME.INP  FOR004
$ASSIGN/NOLOG  CASEFILE.INP  FOR007
$ASSIGN/NOLOG  FILENAME.BIN  FOR008
$ASSIGN/NOLOG  FILENAME.LIS  FOR009
$RUN AGDISP
```

To Invoke AGPLOT

```
@AGPLOT FILENAME
```

will generate

```
$ASSIGN/NOLOG  FILENAME.BIN  FOR008
$ASSIGN/NOLOG  FILENAME.PLT  FOR007
$ASSIGN/USER   SYS$COMMAND   SYS$INPUT
$RUN AGPLOT
```

TABLE 7-3

Interactive Processing of Three Deposition Files
on a UNIVAC 1108

Block 1:

```
@XQT_AGDISP.GODISP

@ASG,UP_PLOT1.,F/100/TRK/500

@COPY_PLOTFILE.,PLOT1.
```

Block 2:

```
@XQT_AGDISP.GODISP

@ASG,UP_PLOT2.,F/100/TRK/500

@COPY_PLOTFILE.,PLOT2.
```

Block 3:

```
@XQT_AGDISP.GODISP
```

Block 4:

```
@USE_11.,PLOT1.

@USE_12.,PLOT2.
```

Block 5:

```
@XQT_AGDISP.GOPLOT
```

Note: An underline _ denotes a single blank space

TABLE 7-3 (Cont'd)

Block 6:

```
@ADD AGDISP.INITIAL
@ASG,A INPUT1.
@COPY INPUT1.,INPUTFILE.
@XQT AGDISP.GODISP
@ASG,A PLOT1.
@COPY PLOTFILE.,PLOT1.
@ASG,A INPUT2.
@COPY INPUT2.,INPUTFILE.
@XQT AGDISP.GODISP
@ASG,A PLOT2.
@COPY PLOTFILE.,PLOT2.
@ASG,A INPUT3.
@COPY INPUT3.,INPUTFILE.
@XQT AGDISP.GODISP
```

Block 7:

```
@RUN,P/B region,account/userid,projectid
@PASSWD password
@ADD BATCHFILE.
@FIN
```

Block 8:

```
*userid/password
@@SEND
```

third set of data is set, and Block 3 is invoked. Note that after Block 3, all plot data is saved, the first set in PLOT1, the second in PLOT2, and the last in PLOTFILE. AGPLOT will first look to PLOTFILE for data; therefore, we need to establish a link to our other files using Block 4. At this point, we invoke AGPLOT with Block 5.

Under multiple file options, AGPLOT will first request the mass fraction for the current data set (the data in PLOTFILE), then attempt to open units 11, 12, 13 etc., until the mass fraction total meets or exceeds unity. In this example, the second file opened will be PLOT1 and the third file opened will be PLOT2. The mass fraction should now equal unity, and AGPLOT will request nozzle flow rate, deposition scale type, etc., to complete the plot. A legend plot will correlate particle size and mass fraction with the specific curves used to plot the deposition.

The batch processor could be used to do the work of Blocks 1, 2 and 3 in a delayed or overnight job. Such a set up could be established for the three deposition runs discussed above by constructing a batch file (called BATCHFILE) with the contents of Block 6 shown in Table 7-3. Here we assumed that the initial file assignments have already been made so that errors will be discovered interactively and not in batch. To run in batch requires the establishment of separate input files (rather than simple editing of INPUTFILE) that can be recovered to run AGDISP. The process involves copying the relevant data into INPUTFILE, running AGDISP, and copying the PLOTFILE results for later processing. In the example shown here, PLOT1, PLOT2, and PLOTFILE will again hold the results needed to invoke AGPLOT to plot multiple ground deposition.

BATCHFILE is invoked by entering the interactive commands shown in Block 7. A separate @RUN must be typed to the screen, with an @PASSWD card, and BATCHFILE added to the runstream with @ADD. An @FIN completes the job deck. Note that with this procedure, Block 7 can be used for any batch file desired, but it must be typed in interactively. Block 6 can be modified with the editor for any specific purpose. Since no checks are made until runtime, there can be no mistakes in the setup and in BATCHFILE if the run is to be successful.

A terminal output file is created for every batch job run at Ft. Collins. This file essentially contains the information printed to the screen by the system and by AGDISP. To recover this file (to see whether the batch run was successful, for example), the user would invoke Block 8 at the point where the system requests USERID/PASSWORD. With an asterisk in front of the userid/password, the system will permit the @@SEND command to recover results. The terminal then becomes inactive, and the user may invoke @RUN to start an interactive job and eventually invoke AGPLOT to plot results.

In all of the above examples, the PRINTFILE was overwritten and not saved. To save printed results for each input file would require additional statements similar to the statements for PLOTFILE.

[illegible] of data is one, and [illegible] is [illegible]. [illegible] [illegible] data is [illegible], the first set [illegible]. [illegible] in [illegible] [illegible] ADVIS will first look to [illegible] for data [illegible] to establish a link to our other files using Block [illegible]. [illegible] PL [illegible] with Block 5.

[illegible] multiple file [illegible] (first [illegible]) [illegible] mass fraction [illegible] the current data set (the data in [illegible]) [illegible] 12, 13 etc., until the mass fraction total [illegible] [illegible] file, the second file [illegible] will be [illegible] [illegible] file [illegible] [illegible] The mass fraction [illegible] nozzle flow rate, [illegible] or angle type. [illegible] [illegible] plot [illegible] correlate particle size and [illegible] with the [illegible] be used to [illegible] the deposition.

[illegible] batch processor could be used to [illegible] Blocks [illegible] [illegible] overnight job. Such a set up [illegible] [illegible] [illegible] [illegible] discussed above by [illegible] [illegible] FILE) with the contents of Block [illegible] shown in Table [illegible]. [illegible] the initial file assignments have already been made [illegible] [illegible] interactively and not in batch. [illegible] [illegible] [illegible] of separate input files [illegible] [illegible] [illegible] that can be recovered to [illegible]. This [illegible] relevant data into [illegible], running ADVISP, [illegible] for later processing. [illegible] example [illegible] will again hold the result [illegible] [illegible] deposition.

BATCHFILE is invoked by entering the interactive command [illegible] A separate [illegible] must be typed to the [illegible] [illegible] FILE added to the functions with [illegible] [illegible] that with this procedure, Block [illegible] can be used [illegible] [illegible] must be typed in interactively. Block [illegible] can be [illegible] for any specific purpose. Since no checks are made until [illegible] can be no mistakes in the setup and in BATCHFILE if [illegible] [illegible] cessful.

[illegible] terminal output file is [illegible] of every [illegible] [illegible] file essentially [illegible] the information [illegible] [illegible] and by ADVISP. To recover this file (to [illegible]) [illegible] cessful, for example), the user would [illegible] [illegible] requests [illegible] With [illegible] [illegible] /password, the system will permit the [illegible] command to [illegible] [illegible] The terminal then becomes inactive, and the user may [illegible] [illegible] interactive [illegible] [illegible]

[illegible] the above examples, the [illegible] was overwritten [illegible] [illegible] results for each input file [illegible] [illegible] [illegible] to [illegible] statements for [illegible]

[illegible]

# 8. ATMOSPHERIC TURBULENCE LEVEL

The second entry on card 0050 is the maximum value of background turbulence $q^2$. This value influences the growth of the variance about the mean particle motion, and the standard deviation of the deposition. The crosswind inputs on card 0028 also produce a turbulence level that gets added to the card 0050 level, since a logarithmic profile generates a turbulence level of

$$q^2 = 0.845 \left[ V(z_r)/\ell n\ (z_r/z_o) \right]^2 \tag{39}$$

where $V(z_r)$ is the velocity at height $z_r$ with surface roughness $z_o$. Under locally neutral atmospheric conditions, the total wind velocity would be used to compute the total turbulence level by the above formula. If the atmosphere is calm, the turbulence level may be taken as 0.0 on card 0050.

For atmospheric conditions other than neutral or calm, estimates of turbulence levels may be obtained by using stability categories (Refs. 34 and 35). Table 8-1 presents these averaged atmospheric categories as a function of surface wind and temperature inversion, while Table 8-2 gives the range in values for turbulence as a function of surface wind and stability category. Selecting the simulation time-of-day and surface conditions permits the selection of the stability category, A through G. This category then provides for the selection of turbulence values consistent with the stability.

TABLE 8-1

Stability Categories in Terms of Wind Speed, Insolation and State of Sky (Ref. 34)

| Surface wind speed (m/sec) | INSOLATION | | | NIGHT | |
|---|---|---|---|---|---|
| | Strong | Moderate | Slight | Thinly overcast or > 4/8 low cloud | < 3/8 cloud |
| < 2 | A | A-B | B | G | G |
| 2-3 | A-B | B | C | E | F |
| 3-5 | B | B-C | C | D | E |
| 5-6 | C | C-D | D | D | D |
| > 6 | C | D | D | D | D |

Notes:

1) for A-B take average values for A and B etc.

2) strong insolation corresponds to sunny midday in midsummer, slight insolation to similar conditions in midwinter. Night refers to the period from one hour before sunset to one hour after dawn. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night, and for any sky conditions preceding or following the night as defined above.

TABLE 8-2

Turbulent Intensities Near Ground Level (Ref. 35)

| | Stability Category | $q^2/V(z_r)^2$ |
|---|---|---|
| A | extremely unstable | 0.365 - 1.2 |
| B | moderately unstable | 0.145 - 0.365 |
| C-D-E | near neutral | 0.025 - 0.145 |
| F | moderately stable | 0.015 - 0.025 |
| G | extremely stable | 0.0 - 0.015 |

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## APPENDIX A: AGDISP SUBROUTINES

This section of the Appendix summarizes the code comprising each subroutine in AGDISP. Figure A-1 presents a flowchart of AGDISP. Table A-1 highlights the important variables used in the program.

AGDISP is the mainline program computing particle motion by a Lagrangian technique. Each data entry is checked and initialization is performed. Card order is maintained by a series of error flags L20, L23, L25, etc. Free format entry requires that all data cards contain the appropriate data, otherwise, an error will be trapped. Inadvertently reaching the end of the data deck also generates an error. All input cards generate output to the terminal. Integration is then performed, after which the final ground deposition is computed, including the effects of evaporation. The generated plot file is used when plotting the trajectories and deposition with AGPLOT.

AGBKG evaluates the background velocity and turbulence level at a specified point. The decay rate, based on the time constant DTAU, is first computed. The simple evaporation model of Trayford and Welch, and the drag law of Langmuir and Blodgett are used. The turbulent scale length and turbulence $q^2$ are then computed. The turbulence may come from superequilibrium or the fixed inputted value modified by other models in the flow. Alternately, the turbulence may be provided in a WAKE plot file. The material-turbulence correlations are then computed. The equations are a result of the assumption of a von Karman spectral distribution. The constants XK1, KX2, XK3 take their limiting values whenever the time constants are within 0.5% of each other. The correlations $\langle ux \rangle$ and $\langle uv \rangle$ are then evaluated. Finally, the needed information at the specified point is saved in the vector DV.

AGBOD computes the rate of change in the wide-body area, as a function of distance behind the aircraft nose, and initializes the turbulent wake parameters when the wide-body effect (with cards 0080 and 0081) is invoked. A three-point, nonuniform derivative formulation is used, with correction at the end points (the nose and tail).

AGBZD evaluates the derivatives for the time-dependent solution of the Betz roll-up methodology. The input parameters are the current values of the variables, the derivatives (to be computed in this subroutine), the starting pointer, maximum pointer, end pointer and total entry pointer of the current vortex circulation distribution. The variables are the radius of the vortex core and the circulation strength of the vortex. At $t = 0$, the radius is zero and the singularity is treated by taking the appropriate limit.

AGBZG initializes the Betz roll-up procedure using the user-inputted circulation distribution stored in common block BETZ. The first section of the subroutine computes the spatial derivative of the circulation along the wing. The circulation distribution is then reexamined to locate where the slope is maximum (these become positions where vortices start rolling up) and where the slope is

minimum (these become the end positions of the vortex circulation patterns). The circulation pointers to start, maximum and end for up to four vortices are then set (more than four vortices invoke an error exit from AGDISP). The initialization is completed by evaluating the derivatives at zero time and initializing all of the parameters pointing in the AGDISP code to vortex center location, strength, canopy effect and unrolled sheet effect. The code then establishes a vortex-dependent time step DTV vector based on 1% of the roll-up time constant.

AGBZI integrates the Betz equations across the time step DELT entered from the AGDISP code. The first section of the subroutine establishes the time step and number of steps to integrate based on the computed values of DTV and the vortices not yet fully rolled up. Each vortex is treated separately by first predicting its new values of radius and circulation, then solving for the derivatives at these values and correcting the solution. The centroid of the vortex is computed based upon how much circulation has rolled into the vortex at each time step. The incremental movement of the vortex for each Betz time step is added to the current position of the vortex (this position may be influenced by the other background features incorporated in AGDISP), and fully rolled-up vortices are flagged with zero sheet strength. Lastly, the unrolled sheet lengths are determined.

AGCDS writes the input data deck at the front of the plot file. If card 0005 is present, AGCDS will examine the case file to locate the proper case, then overlay these cards with any cards in the input deck. The resulting run file will be read in AGDISP as the input runstream.

AGCRS computes the local value of turbulent energy associated with the discrete crosswind velocity profile shape entered with 0029 cards. A three-point, nonuniform derivative formulation is used to compute the velocity gradient. Locally neutral superequilibrium is assumed to compute the QV profile.

AGDAT1 processes half of the input cards.

AGDAT2 processes the other half of the input cards.

AGEQN monitors the integration of the equations. Initially, all positions are stored and initial derivatives determined. Integration then proceeds step by step to the maximum inputted time. The WAKE plot file, Betz, canopy, propeller or jet engine, helicopter and wide body are updated where applicable. Solutions terminate at the deposition height. Since the vortices move under the influence of one another and their ground images, their positions are also adjusted. Any material that impacts the surface is flagged and its final size is computed. Termination is checked for evaporation, maximum time, and ground impact; and plot save is invoked. If termination exists, transfer is returned to AGDISP; otherwise another time step is taken.

AGGLQ is a Gauss-Legendre integration routine used to determine the area under the inputted discrete function between inputted starting and

ending points. When $M$ is equal to one, the integrand is multiplied by $y$.

AGINT is a linear interpolator extracting the value of the inputted discrete function at the inputted position.

AGMAT fills the six-by-six matrix array for the unknowns $\langle uu \rangle$, $\langle vv \rangle$, $\langle ww \rangle$, $\langle uv \rangle$, $\langle uw \rangle$ and $\langle vw \rangle$ by superequilibrium for a given value of $q^2$. The linear equations are solved to determine the difference between $q^2$ and $\langle uu \rangle + \langle vv \rangle + \langle ww \rangle$.

AGPAD computes the displacement thickness of the plant canopy and initializes the effective circulation integrals. The displacement thickness is assumed to represent the effective surface roughness the canopy gives the atmospheric flow above it. Within the canopy, the crosswind velocity and turbulence are assumed to behave linearly with height. On additional calls, AGPAD computes the vortex circulation reduction resulting from interactions with a canopy. Essentially, the scrubbing of the vortex acts as a drag on the wake flow field. The drag translates into an effective vortex strength smaller than the noncanopy value. In this subroutine vortices are checked for whether they have penetrated the canopy; if so, an integration across the portion of the vortex interacting with the plant area is taken, a simple time integration is performed, and the vortex strength reduction factor is computed. The reduction factors FACR and FACL modify the vortex strengths, unrolled sheet strengths, propeller swirl and helicopter effects.

AGSAV writes the step integration results from AGDISP to the plot file (mean position, standard deviation, etc.) and the line printer (all variables for all nonimpacted material). With the proper flags set, this routine will also write to the plot file and print vortex center location and powerplant midpoints.

AGSUP is the controlling routine for superequilibrium. Given the six spatial derivatives in the AGDISP code and the local scale length, the superequilibrium equations are iterated for the values of $\langle uu \rangle$, $\langle vv \rangle$ and $\langle ww \rangle$. The maximum gradient is used to normalize the solver, an approximate result is selected, and then an accurate solution is found by stepping in $q$ until a zero crossing is found by bisection. This result produces the values of turbulent energy unnormalized by scale length and the normalizing velocity gradient.

AGSVE computes the incremental background velocity arising from the unrolled Betz sheets. In this case, the sheets are represented by a constant circulation sheet of vorticity, and the resulting flow is analytically determined. The singularity in the vicinity of the sheet is controlled by imposing a linear profile in $z$. As the Betz procedure continues, the sheet becomes shorter until it is finally rolled up.

AGVEL computes the mean velocity components $U$, $V$, and $W$ at the position $(x,y,z)$. Each vortex, its reflecting image across $y = 0$ and their images across $z = 0$ are used to compute the overall velocity

increment. The standard potential vortex velocity field producing a velocity normal to the radius vector is broken into its (y,z) components and modified by FACR and FACL for the presence of a canopy and GDKV for circulation decay. The unrolled sheet effect (with image sheets) is added, as are the helicopter, powerplant, wide body and mean crosswind modified by the canopy. Alternately, the WAKE plot file is quizzed to return the appropriate velocity components.

AGWAK processes calls for information in the WAKE plot file. The file is sequential binary, with a first record of the number of y and z mesh points, a second record of the values of the y mesh, and third record of the values of the z mesh. Following records consist of a time entry followed by all y data values for each z row for each variable. The second section recovers the WAKE plot file data for the desired time T . Interpolation between time steps is performed every one-tenth of the interval; otherwise the data arrays in common block WAKE are not updated. The file is rewound, the initial data skipped, and the pertinent time step bracketed. Linear interpolation is then performed, and the next time check in computed. When the end of the WAKE plot file is reached, the last time entry data is used for the duration of the AGDISP run. The third section linearly interpolates the data array read from the WAKE plot file for the variable desired $(V, W, q^2)$ at the position (y,z) . A warning message is written the first time spatial extrapolation beyond the WAKE plot file grid coordinate is invoked, even though extrapolation may continue indefinitely thereafter.

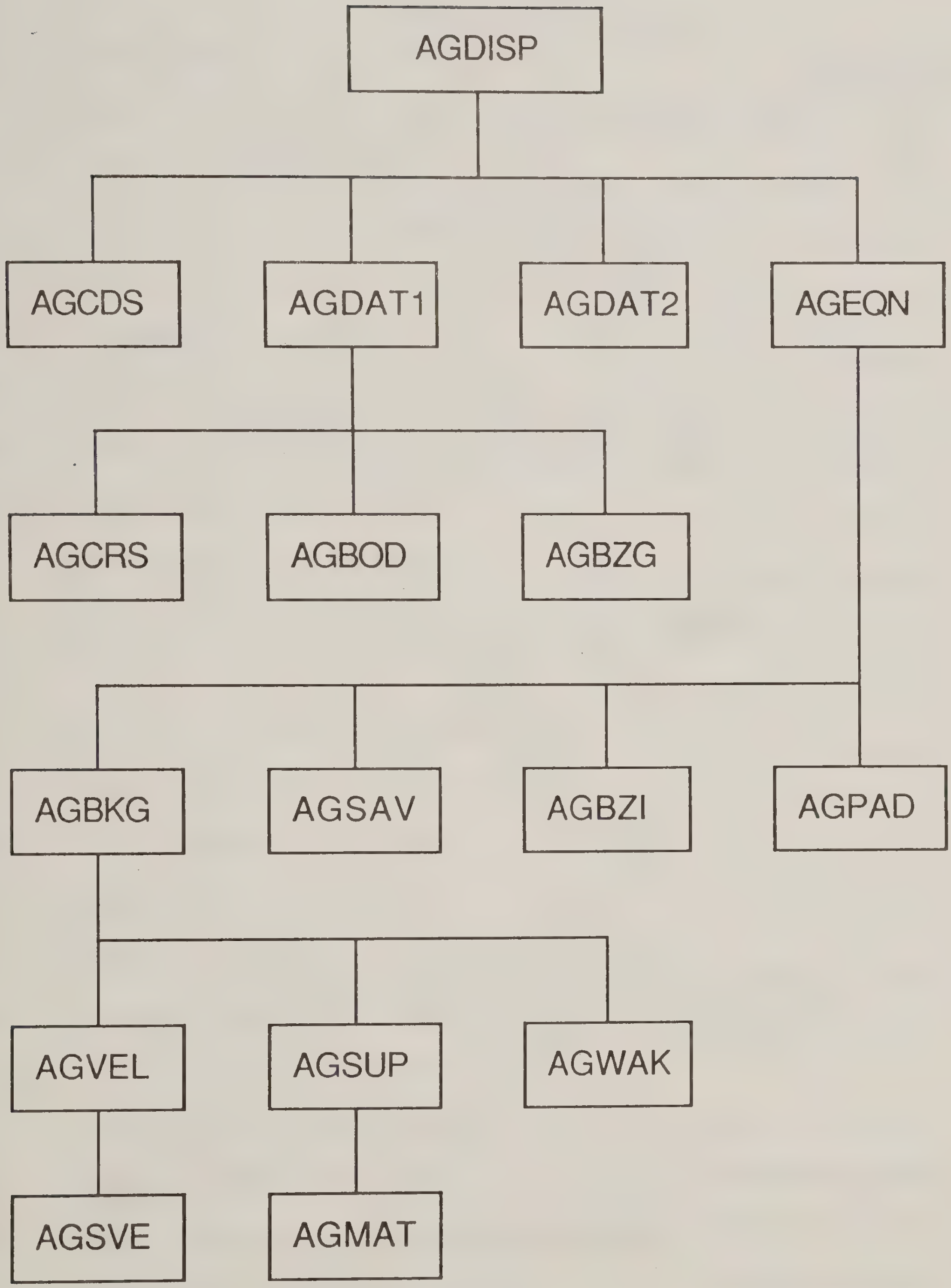


Figure A-1. AGDISP summary flowchart.

TABLE A-1
AGDISP Variable List

| NAME | DESCRIPTION |
|---|---|
| AS | airplane planform area |
| AV | vector: inputted plant area fraction |
| BDOT | helicopter blade rotation rate |
| CA | crosswind direction angle |
| CD | airplane drag coefficient |
| CHF | helicopter transition factor (hover to vortex pair) |
| CHG | helicopter circulation factor (vortex pair) |
| CHQ | wide-body wake turbulence factor |
| CHR | wide-body wake radius factor |
| CHS | wide-body interpolated cross-sectional area |
| CHW | helicopter downwash factor (hover) |
| CPUR | powerplant wake turbulence factor |
| CPIX | powerplant virtual origin factor |
| CTA | cosine of terrain angle |
| DBOD | maximum diameter of wide body |
| DCUT | material diameter below which evaporation ceases |
| DEA,DEB DEC | parameterized evaporation constants |
| DELT | integration time step |
| DENF | specific gravity |
| DGV | vector: Betz circulation derivatives |
| DIAM | material diameter |
| DIST | vertical distance |
| DMCV | vector: material volume ratio at surface impact |
| DSYM | vector: unrolled Betz sheet length left-of-centroid |

TABLE A-1 (Cont'd)

| NAME | DESCRIPTION |
|---|---|
| DSYP | vector: unrolled Betz sheet length right-of-centroid |
| DTAU | material relaxation time |
| DTEMP | evaporation wet bulb temperature difference |
| DTV | vector: Betz integration time step for each vortex |
| DZBP | incremental vertical distance from DIST to biplane wing |
| EDNV | vector: present time step material diameter |
| EDOV | vector: previous time step material diameter |
| ETA | airplane propeller efficiency |
| ETAU | evaporation relaxation time |
| FACL | vector: plant canopy circulation reduction - left vortices |
| FACR | vector: plant canopy circulation reduction - right vortices |
| FL | vector: plant area fraction integral - left vortices |
| FR | vector: plant area fraction integral - right vortices |
| GAMMA | vortex circulation strength |
| GDK | vortex decay constant |
| GDKV | vector: vortex decay factor for each vortex |
| GSAV | vector: Betz average sheet circulation per unit length |
| GV | vector: inputted Betz circulation |
| G2PI | vector: circulation divided by two pi |
| HHEL | initial height of helicopter rotor plane above surface |
| HTPAD | plant canopy maximum height above surface |
| ICARD | running count of input cards |
| ICV | vector: input card numbers |
| JHEL | dividing streamline flag |
| LEVAP | evaporation flag |

TABLE A-1 (Cont'd)

| NAME | DESCRIPTION |
|---|---|
| LHFPL | half-plane/full-plane flag |
| LMCRS | mean crosswind flag |
| LMVEL | mean velocity flag |
| LPART | nozzle flag |
| LQQSE | turbulence flag |
| LZERO | centerline nozzle flag |
| Lmn | card 00mn flag |
| MEV | vector: end points location for all Betz vortices |
| MSV | vector: starting points location for all Betz vortices |
| MXV | vector: maximum points values for all Betz vortices |
| NBOD | total number of wide-body points |
| NBTZ | number of Betz vortices |
| NCRS | number of discrete crosswind velocity data points |
| NDAT | card input file unit number |
| NDEF | default input file unit number |
| NENDF | wake plot file record position counter |
| NEXTF | wake plot file extrapolation flag |
| NF | wake plot file record read counter |
| NGAM | number of discrete inputted Betz circulation data points |
| NMAX | maximum admissible grid positions in wake plot file |
| NOUT | terminal output unit number |
| NPAD | number of discrete inputted plant area fraction data points |
| NPLT | plot output file unit number |
| NPRP | total number of powerplant units |
| NPRT | printer output file unit number |

TABLE A-1 (Cont'd)

| NAME | DESCRIPTION |
|---|---|
| NPTJ | frequency of trajectory plot output file writes |
| NPVL | plot save flag for vertical velocity |
| NPVX | frequency of vortices/centerlines plot output file writes |
| NPXX | plot save flag for mean velocities |
| NSTEP | step number counter |
| NVAR | total number of nozzles |
| NVOR | total number of vortices |
| NWPF | wake plot file unit number |
| NY | total number of horizontal points in wake plot file |
| NZ | total number of vertical points in wake plot file |
| PGBP | biplane circulation factor |
| PSBP | biplane semispan factor |
| PV | vector: inputted vertical locations of crosswind velocity |
| QQBOD | centerline turbulence level in wide-body wake |
| QQMX | constant background turbulence level |
| QV | vector: computed crosswind turbulence level |
| REYNO | Reynolds number based on relative velocity |
| RBOD | radius in wide-body wake |
| RHEL | helicopter blade radius |
| RPRP | radius of propeller/jet flow field |
| S | airplane semispan |
| SBV | vector: wide-body area |
| SRV | vector: vortex core radius |
| STA | sine of terrain angle |
| T,TIME | integration time |

TABLE A-1 (Cont'd)

| NAME | DESCRIPTION |
|---|---|
| TA | terrain slope angle |
| TDOT | propeller shaft rpm |
| TMAX | maximum integration time |
| TMCV | vector: time of material impact with surface |
| UO | aircraft flight speed |
| USK | shear stress constant for crosswind evaluation |
| UV | vector: inputed crosswind velocity |
| VPRP | propeller tip speed |
| WHEL | helicopter downwash velocity at blade plane |
| WT | weight |
| WTAU | turbulent relaxation time |
| XBOD | axial distance from airplane nose to nozzles |
| XBV | vector: body axial distance |
| XMU | helicopter forward advance ratio |
| XNV | vector: new time location values |
| XO | axial distance measured from nozzle |
| XOV | vector: old time location values |
| YBAL | vector: horizontal location of left vortices |
| YBAR | vector: horizontal location of right vortices |
| YBOD | horizontal location of wide body centerline |
| YHEL | horizontal location of helicopter centerline |
| YPRP | vector: horizontal location of powerplant centerline |
| YV | vector: inputed discrete stations for Betz circulation |
| ZBAL | vector: vertical location of left vortices |
| ZBAR | vector: vertical location of right vortices |

TABLE A-1 (Cont'd)

| NAME | DESCRIPTION |
|---|---|
| ZBOD | vertical location of wide-body centerline |
| ZHEL | vertical location of helicopter centerline |
| ZO | surface roughness height |
| ZOPAD | plant canopy effective surface roughness height |
| ZPRP | vector: vertical location of powerplant centerline |
| ZREF | apparent surface height |
| ZV | vector: inputted vertical locations of plant area fraction |

## APPENDIX B: AGPLOT SUBROUTINES

This section of the Appendix summarizes the code comprising each subroutine in AGPLOT. Figure B-1 presents a flowchart of AGPLOT. Table B-1 highlights the important variables used in the program.

AGPLOT is the mainline program for plotting the results from AGDISP. The program first reads the plot file and computes minimum and maximum values, and identifies file options. The user then selects from a menu of possible plot options, including plotting mean trajectories, trajectories including the turbulent standard deviation, trajectories of vortices or powerplant centerlines, ground deposition, equivalent Gaussian distribution, or profiles of crosswind velocity, plant area density, droplet diameter or droplet velocity. More than one option may be invoked before program exit.

AGADD computes a running total (as a function of time) of the deposition by adding contributions incrementally.

AGASC computes minimum, maximum and increment scale values to include available data and present a visually pleasing scale division. The algorithm uses a base ten power law to decide on scale divisions.

AGCAN computes the incremental Gaussian deposition through a canopy. Each released material moves through the canopy, and its deposition effect is summed and contour plotted by the user.

AGCHK verifies the appropriateness of the scaling information requested by AGPLOT of the user. In all cases, the scale must be monotonically increasing with a positive spacing between scale divisions and an integer number of scale divisions, not to exceed ten.

AGCON computes the continuous ground deposition pattern.

AGDEP evaluates the incremental continuous deposition with the complementary error function.

AGDFT computes the drift fraction of the simulation.

AGDRP reads the plot file to recover the time history of a specific droplet diameter undergoing evaporation, the canopy parameter or the mean velocities of a droplet.

AGDRW draws a data curve. If a plane of symmetry exists, the data is translated to the negative axis and also drawn.

AGEQD computes the equivalent Gaussian distribution. The mean horizontal and vertical positions and standard deviations are summed over all material in the solution plane, and the figure of merit is computed.

AGEQG interprets the plot file to construct an equivalent Gaussian profile distribution at every time step. Two passes are made through the plot file. The first pass computes the equivalent Gaussian, figure of merit and vertical velocity criterion at every time in the plot file, and displays to the screen the points of maximum and minimum figure of merit, material impact with the surface, and equivalent Gaussian impact with the surface. From this information the maximum figure of merit is determined and the program locates that time in the second pass to create the equivalent plot.

AGEQP sets up and plots the equivalent Gaussian and material isopleths.

AGGRD computes the Gaussian ground deposition pattern. Each impacting material in the AGDISP simulation hits the surface at a known y position with a known variance. Adding all locations with their known impact sizes produces the deposition pattern along the surface.

AGIMP computes the velocity normal to the collection device, the impaction parameter, impaction efficiency and incremental material deposition in a time step.

AGPLT is the plotting subroutine that uses graphics subroutine calls to perform the actual plotting. The screen is first cleared, then axes are established and plotted and a wing schematic is drawn. The plot file is read so that nine points are plotted at a time, drawing the mean trajectories (including the image if desired), the standard deviation paths, the vortices and powerplant centerline paths, tag markers at the desired interval, array profiles, (including ground deposition), and equivalent Gaussian profiles.

AGRPF rereads the front of the plot file to recover input card data for crosswind velocity or plant area profiles.

AGSCP establishes curve patterns for CALCOMP plotting at Dugway.

AGSCR manipulates the screen options available on the Data General.

AGSET completes the plotting setup by checking for a full-plane plot (with a half-plane solution), autoscaling axes, and tag markers at specified time intervals. The plotting process is then invoked with a call to AGPLT.

AGSPD uses the stored plot file variables to determine the plotting coordinates of the standard deviation, normal to the instantaneous direction.

AGSRF oversees computation of Gaussian deposition as a specified collection device, at a specified location (y,z) , with a specified unit normal.

AGSUM integrates the deposition along the surface.

Graphics calls on the Data General invoke GKS subroutine calls. They include the following:

GKS_CLEAR clears the graphics screen.

GKS_CLOSE ends the graphics session.

GKS_DRAW plots the data points by straight lines after setting up the axes.

GKS_GPL plots the data points.

GKS_OPEN initializes the graphics session.

GKS_Q_WS_WIN returns the pixel size of the plotting device.

GKS_QPRINT sends hardcopy to the output device.

PLDG plots pixel data.

Screen calls on the Data General invoke the following subroutine calls:

FREAD recovers real number information from the user.

IREAD recovers integer number information from the user.

SCREEN_INIT initializes the screen.

SCROLL perform a scroll of the data screen

SREAD recovers character information from the user.

SSCREEN rapidly replace screen contents.

SWRITE writes information to the screen.

Graphics calls at C.D.I. and on IBM PC/XT/ATs are invoked with Tektronix 4025 calls. These calls write plot data to the screen or a data file for later viewing. The subroutines invoked during the running of AGPLOT include the following:

PLHC completes the plot.

PLLN sets the line type.

PLNT sets up scale notation and labels.

PLPL plots the data points (connected by straight lines).

PLSC initializes the graphics area and scale increments.

PLST writes a character string.

PLTT establishes the default graphics parameters.

Graphics calls at Dugway are invoked with CALCOMP subroutine calls. These calls write plot data to a magnetic tape that is then transferred to the CALCOMP plotter for post processing. The subroutines invoked during the running of AGPLOT include the following:

AXIS positions and plots the scales and labels of the plots.

DASHS sets dashline mode characteristics for patterned lines.

FACTOR adjusts the size of the plot (at Dugway the factor entry is 0.5).

LINE plots the data array.

PLOT positions the plot origin.

PLOTS initializes the CALCOMP plotting operations.

SYMBOL positions and plots titles.

Graphics calls at Ft. Collins are invoked with DISSPLA subroutine calls. These calls establish a temporary disk file that contains all the necessary plotting information. Post processing after AGPLOT (by invoking DISSPLA) permits this file to be interpreted, and allows the plotting images to be placed on the Tektronix screen. The subroutines invoked during the running of AGPLOT include the following:

AREA2D specifies the subplot area, the area between the axes where plotting will occur.

COMPRS forces DISSPLA to create a temporary disk file ("metafile").

CURVE plots a two-dimensional set of data.

DASH invokes an interrupted line (dashed) pattern.

DONEPL terminates a plotting session (which can include several plots).

ENDPL ends a specific plot.

GRACE sets a margin around the subplot area beyond which plot curves are not plotted.

GRAF sets up the basic scale axes for a plot.

HEADIN defines a plot title.

HEIGHT specifies the height of the text (also adjusts scale label height).

INTNO sends an integer label to the plot.

MESSAG sends a message label to the plot.

MRSCOD specifies the pen up-down pattern for user-defined curves.

| | |
|---|---|
| NOCHEK | suppresses the listing of plotted points outside the grace margin. |
| PAGE | sets the overall plot size (including scales, labels, and plot title). |
| PHYSOR | defines the absolute physical origin of the plot. |
| RESET | resets a parameter to its default value (in this case it "turns off" the dash line option to give solid lines). |
| SETEND | changes the ending string termination character. |
| SIMPLX | invokes the DISSPLA SIMPLX character font. |
| XNAME | titles the X (horizontal) axis |
| XTICKS | sets the number of X axis tick marks. |
| YAXANG | sets the angle of the Y axis scale labels. |
| YNAME | titles the Y (vertical) axis. |
| YTICKS | sets the number of Y axis tick marks. |

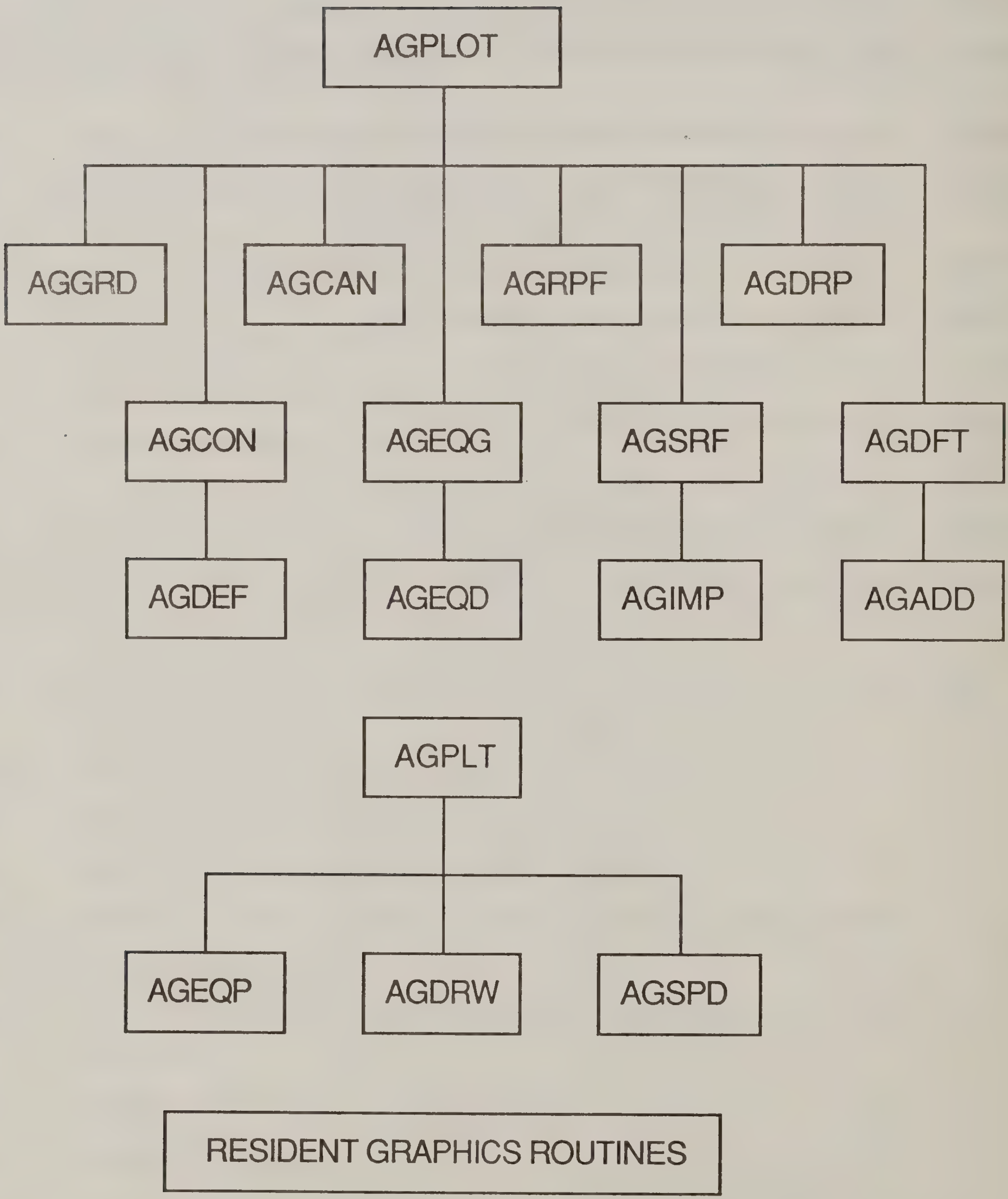


Figure B-1. AGPLOT summary flowchart.

TABLE B-1
AGPLOT Variable List

| NAME | DESCRIPTION |
|---|---|
| CBAR | equivalent Gaussian magnitude |
| DCV | vector: material diameter factors |
| DELT | tag time increment |
| DIAMV | vector: material diameter |
| DIST | initial vertical distance from surface to aircraft wing |
| DMCV | vector: material volume ratio |
| DV | vector: horizontal spread and location at surface impact |
| DZBP | incremental vertical distance from DIST to biplane wing |
| FOM | equivalent Gaussian figure of merit |
| FV | vector: mass fraction |
| GVEC | vector: ground deposition |
| ICV | vector: surface impact flag |
| LAPLT | array plot flag |
| LEPLT | equivalent Gaussian distribution plot flag |
| LFOLD | symmetry plot flag |
| LMPLT | mean trajectory plot flag |
| LPRP | flag for powerplant centerlines to plot |
| LSPLT | standard deviation trajectory plot flag |
| LTPLT | tag plot flag |
| LVEL | flag for number of variables present on plot file |
| LVOR | flag for vortex centroids to plot |
| LVPLT | vortices/powerplant trajectory plot flag |
| LZERO | centerline nozzle flag |
| NINU | terminal input unit number |
| NPLT | plot input file unit number |

TABLE B-1 (Cont'd)

| NAME | DESCRIPTION |
|---|---|
| NOUT | terminal output unit number |
| NVAR | total number of nozzles |
| S | aircraft semispan |
| TA | terrain slope angle |
| TIME | simulation time |
| TMAX | maximum simulation time |
| UO | flight speed |
| WR | velocity ratio for figure of merit |
| WTN | terminal velocity |
| XFn | figure of merit integrals (n = 1 to 4) |
| YCB | equivalent Gaussian horizontal position |
| YGMN | minimum horizontal value for ground deposition |
| YGMX | maximum horizontal value for ground deposition |
| YMAX | horizontal axis plot scale maximum |
| YMIN | horizontal axis plot scale minimum |
| YMMN | minimum horizontal value for mean trajectories |
| YMMX | maximum horizontal value for mean trajectories |
| YSB | equivalent Gaussian horizontal standard deviation |
| YSMN | minimum horizontal value for spread trajectories |
| YSMX | maximum horizontal value for spread trajectories |
| YVMN | minimum horizontal value for centerline trajectories |
| YVMX | maximum horizontal value for centerline trajectories |
| ZCB | equivalent Gaussian vertical position |
| ZGMN | minimum vertical value for ground deposition |
| ZGMX | maximum vertical value for ground deposition |

TABLE B-1 (Cont'd)

| NAME | DESCRIPTION |
|---|---|
| ZMAX | vertical axis plot scale maximum |
| ZMIN | vertical axis plot scale minimum |
| ZMMN | minimum vertical value for mean trajectories |
| ZMMX | maximum vertical value for mean trajectories |
| ZREF | surface reference height |
| ZSB | equivalent Gaussian vertical standard deviation |
| ZSMN | minimum vertical value for spread trajectories |
| ZSMX | maximum vertical value for spread trajectories |
| ZVMN | minimum vertical value for centerline trajectories |
| ZVMX | maximum vertical value for centerline trajectories |